COMMERCIAL POULTRY NUTRITION

3rd edition

BROILER CHICKENS

BROILER BREEDERS

LAYING HENS

GAME BIRDS

PET BIRDS

TURKEYS

RATITES

DUCKS

GEESE

S. Leeson
J.D. Summers

Nottingham University Press

COMMERCIAL POULTRY NUTRITION
THIRD EDITION

by

STEVEN LEESON, Ph.D.
Professor of Animal Nutrition

and

JOHN D. SUMMERS, Ph.D.
Professor Emeritus

Department of Animal and Poultry Science
University of Guelph
Guelph, Ontario, Canada

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I. Leeson, S., Summers, J.D.
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PREFACE

The first edition of this book was published in 1991, while the second edition followed in 1997. It has been an interesting exercise to follow the development of poultry production over this time, and to encapsulate ideas of associated changes in nutrition and feeding management. For example, in 1991, the emphasis in broiler nutrition was on maximizing growth rate, together with the new approach of considering breast meat yield. In 1997, the concept of compensatory growth was emphasized, as a necessary management tool to control metabolic disorders. In the intervening eight years, poultry geneticists have obviously reduced the incidence of these disorders, and so we are once again considering rapid growth throughout the entire grow-out period. It is such evolving circumstances within the industry that dictate the need for periodic reappraisal of our feeding programs.

We have changed the layout of the book to accommodate a two-column presentation of material. In response to reader requests, we have also included commercial data on the nutrient requirements of layers, broilers and turkeys. This data is taken from Management Guides available in early 2004. We realize that such information changes as bird genetics change. The reader should always source the latest information available on a specific breed, from the breeding company, and use this information, rather than that presented in this book as the most accurate assessment of nutrients for a specific strain.

Many of the ideas in this book are based on work carried out in the Department of Animal and Poultry Science at the University of Guelph. In this regard, we are indebted to the many sponsors of our research program, and in particular, the on-going support of the Ontario Ministry of Agriculture and Food, Guelph, Ontario.

Special thanks to Laurie Parr for her conscientious effort in typing the original version of the book, and to Ford Papple of Papple Graphics for his assistance and ideas with the layout and design. Thanks to Linda Caston for again proof reading numerous versions of the book, and her attention to detail is much appreciated. Also thanks to Greg Hargreave, Baiada Poultry for agreeing to proof read the final version. Greg's constant reminder of the importance of brown-egg layers is much appreciated.

Steven Leeson and John Summers
Guelph, 2005

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CHAPTER 1

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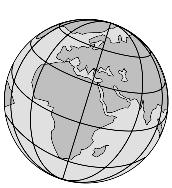
1.1 World Animal Production

Production of most farm animal species has increased over the last 10 years, and predictions are for this trend to continue in the near future. Poultry has seen the greatest increase in production and again, this trend will likely continue. Both poultry meat and eggs are well positioned to meet demands for increased supply from our growing world population. Prediction of world populations is always subject to adjustment, but it seems as though we will have around 7 billion people to feed by 2008. However, an obvious trend occurring is that this population is quickly aging and also living in urban settings of ever increasing size. Today almost 2% of the world's population live in the 10 largest cities in the world, and by 2008, we will likely have 20 cities with populations in excess of 10 million people. These large urban populations obviously rely almost 100% on food supply from rural areas. Traditionally such rural food supply has been grown adjacent to the urban populations, but this situation is becoming increasingly more difficult as these urban populations reach 10-15 million. National and international movement of feed and food will become critical to feeding these large expanding populations. The population in the developed world is predicted to change little in the next 10 years, and so virtually all growth will be in developing countries, and especially in Africa and Asia. With its unpredictable weather patterns, Africa has always had difficulty feeding its growing population, and with increased urbanization, this situation will only deteriorate.



In all countries, there is an aging of the population, and it is predicted that the proportion of people ≥ 60 years of age, will double in the next 30 years. The purchasing power of many such individuals may not be adequate to sustain their usual diet supply. Up to now, and in the near future, we have been able to meet increased demands for food through a combination of increased supply coupled with improved production efficiency. Such improvements in efficiency of production will allow us to gradually upgrade the general nutritional status of the world population as a whole and it is evident that

the poultry industry is playing a major role in this important development. In the past, we have had to face criticism of the energy used in animal production and especially from the point of view of the inefficiency of consuming animal vs. vegetable protein. Of the total energy used by most developed countries, less than 4% is used for food production. During this food production, by far the greatest quantities of energy are used during processing and household preparation to meet the stringent demands of the consumer. Consequently, of the 4% of energy used by the agrifood business, only 18% (or 0.7% of total energy needs) is actually used in primary animal production. Increased human consumption of vegetable proteins as an alternative to meat and eggs has failed to materialize, essentially due to excessive energy use necessary during manufacture, which is the same criticism originally aimed at animal production. The production of synthetic meat analogues is thus very energy intensive, and their limited impact over the last decade attests to problems with economic viability and/or consumer acceptance. With the economy of many third world countries improving, there appears to be increased demand for animal products and especially poultry meat and eggs.

In developed countries, the current concerns regarding meat and eggs are not lack of supply, but rather wholesomeness and food safety. The concern about genetic modification of plants and animals quickly evolved in Europe, such that currently their use is not allowed in food production. Many plant species such as corn and soybean meal are now routinely genetically modified and used as ingredients in diets for poultry and other animals in many countries.

Concern about using animal proteins in diets for farm animals also arose in Europe following the outbreak of BSE in the mid 1990's. Europeans are still uncertain about the health status of their ruminant animals, and the ban on using products such as meat meal continues. While it is possible to formulate diets without meat meals, it is more expensive, and does add a major financial burden on most animal industries since they have to find alternative means of disposal of waste by-products.

It is impossible to produce meat or eggs that are guaranteed to be free of pathogens. A non-tolerance scenario for organisms such as salmonella is untenable, and any such regulations are unrealistic. Certainly there will be increased emphasis on pathogen reduction, and both the poultry meat and egg industries have made significant progress with programs such as HACCP at processing plants, feed mills and poultry farms. Feed is one potential route of entry for pathogens into meat and eggs, and so formulation will have to be modified, or alternate additives used, to try to reduce pathogen load of feed to acceptable levels of tolerance. Feed processing is now viewed with an aim to pathogen control, in addition to concerns about feed intake and bird growth. There will undoubtedly be reduced emphasis on antibiotic growth promoters as are now commonly used in broiler and turkey production and this situation adds even more demand on feed pathogen control programs.

On a more positive note, the production of so-called designer foods continues to increase; with the best example being omega-3 enriched eggs. It is simple to modify the fat-soluble nutrient profile of meat and eggs, and so there will be an increased demand, within niche markets, for food products modified in relation to improved human nutrition.

1.2 Poultry Meat Production

The broiler chicken industry has shown unparalleled growth over the last 30 years, although there are now signs of a maturing market in many countries. The industry is relatively easy to establish and while there are regional differences, production systems in most countries are modeled in a similar manner. Because of the increased growth potential in modern strains of broiler, it is now realized that some degree of environmental control is essential. Such systems can be full environmental control through to curtain sided houses in tropical countries. Even with the latter, cheaper type housing, it seems essential to ensure adequate air movement and so tunnel ventilation has become popular over the last 10 years. Optimum growth rate cannot be achieved much beyond the range of 15-30ºC and so the ventilation systems are designed to hopefully maintain the birds' environment within this temperature range.

Chicken is usually the least expensive meat in most countries and consequently it is first or second for *per capita* consumption. This competitive situation has occurred due to continued improvements in efficiency of production that often necessitate acceptance of new ideas and innovations by poultry producers and agribusiness. On the other hand, production systems for competing meat products have shown little change over the last two decades. Interestingly, the swine industry is now starting to use 'poultry' models in production systems.

Much of the success of the chicken meat industry relates to development of new consumer products, largely because of continued advances in further processing. The most successful single product is undoubtedly the 'chicken nugget', now featured by most fast food and retail outlets. Over the last 10 years, some 30,000 non-chicken fast-food outlets in North America have added chicken products to their menu, and during special advertising campaigns, chicken products can be the leading sales item over such conventional products as hamburgers. So-called 'fast-food' stores are increasing in number in Europe, in Asia and in South America, and this will likely lead to increased demand for chicken. In addition to developing new uses for conventional parts of the chicken and turkey carcass, the industry has also been successful in developing technology to use its own 'by-products' and then finding markets for these (or vice versa). The demand for chicken wings and chicken feet together with mechanically deboned meat exemplify these types of products. In addition to increasing overall poultry meat consumption, these products also lead to improved overall efficiency of production and help maintain the economic advantage seen with poultry meat.

Poultry meat is also ideally suited in terms of meeting demands for leaner meat by health conscious consumers. There has been considerable publicity over the last few years concerning the relative fat content of various meats, yet the fact remains that when comparisons are conducted on comparable products, poultry meat is the leanest product. Comparison of a highly trimmed steak or pork chop vs. a whole broiler carcass certainly reduces the advantage usually seen with poultry. However, the valid comparison is trimmed steak vs. poultry breast fillet, in which case the poultry product is by far the leanest. Broiler chicken and especially turkey are therefore ideal products for segments of the food industry wishing to provide low-fat meals. Poultry meat also has the almost unique advantage of not being discriminated against due to religious or cultural beliefs, making poultry products popular with airlines, hotels, institutions, etc.

The poultry meat industry has come under recent scrutiny regarding the use of growth promoters in the feed. When these are removed from diets, broilers most frequently develop necrotic enteritis and coccidiosis, and so their main mode of action seems to be control over clostridial infection. When growth promoters are not used in the feed, then alternate strategies such as competitive exclusion, water acidification, man-nan-oligossaccharides and pro- and prebiotics are often considered. Ironically, while growth promoters are often banned as feed additives, an alternative strategy is to use them as water medication. Table 1.1 shows total poultry meat production worldwide, and in major producing areas, while Tables 1.2 and 1.3 show the break-down for broiler and turkey meat production.

Table 1.1 Poultry meat production (million tonnes)

	1993	*2005*
World	*48*	*80*
North America	*15*	*25*
S. America	*6*	*12*
Europe	*10*	*13*
Asia	*14*	*22*

Table 1.3 Turkey meat production (million tonnes)

	1993	*2005*
World	*4*	*5.5*
North America	*2*	*3*
S. America	*0.1*	*0.3*
Europe	*1.5*	*1.8*
Asia	*0.1*	*0.2*

Table 1.2 Broiler meat production (million tonnes)

	1993	*2005*
World	*41*	*68*
North America	*13*	*21*
S. America	*5.5*	*11.5*
Europe	*9*	*10.5*
Asia	*12*	*20*

Table 1.4 Egg production (million tonnes)

	1993	*2005*
World	*38*	*57*
North America	*6*	*8*
S. America	*2.5*	*3.4*
Europe	*10*	*10*
Asia	*18*	*32*

1.3 Egg Production

The egg industry is enjoying increased production as consumers become more educated about the nutritive value of eggs and as more eggs are processed. The mis-information from the 1980's regarding the relationship between cholesterol intake and blood cholesterol levels has been superceded by pertinent information detailing the relevant contribution of various dietary nutrients to serum cholesterol in humans. Eggs are relatively inex-pensive per unit of protein and energy contained in yolk and albumen, and so egg consumption continues to increase in developing countries.

The egg industry produces either brown- or white-shelled eggs. While white eggs predom-inate in North America, consumers in many

countries demand a brown egg. Unfortunately, such demand is based on the naive view that brown-shelled eggs are more nutritious or wholesome. In developing countries, this myth is compounded with the demand for a highly pigmented yolk, and both of those factors add to the cost of production. North America has also seen great success in production of designer eggs, since some 5% of shell eggs are now enriched with nutrients such as omega-3 fatty acids and vitamin E. This profitable segment of the egg industry has not merely displaced demand for normal eggs, but rather has created a genuine increased demand for eggs and egg products.

In North America, the most dynamic segment of the egg industry relates to processing and further processing of eggs, paralleling the success seen in the poultry meat industry. By 2008, it is estimated that at least 50% of eggs in North America will be processed in some way or expressed in an alternate way, only 50% of eggs will be marketed in the shell. Expansion of egg processing is raising new challenges to production, where for instance egg mass is much more important than egg size *per se*, and where shell quality is of lesser importance. It is likely that the white-egg strains will be developed for the processing industry, while brown-shelled strains will be selected for characteristics important for the shell egg market. Disposal of the end-of-lay bird is becoming more difficult in many regions and so it seems important to develop new food products from this potentially valuable resource. Converting spent fowl into animal feed ingredients and especially for layer feed seems a very shortsighted approach in terms of consumer perception. Table 1.4 shows global and regional egg production.

1.4 Future Considerations for Poultry Nutrition

Over the last 20 years, developments in poultry nutrition have paralleled, or made possible, increased productivity of the various poultry industries. As production conditions and goals have changed, we have been able to revise our estimates of nutrient requirements. Greater variation in production goals has imposed some degree of complication to feeding programs, because 'global' recommendations are now often not applicable. The future emphasis in poultry nutrition must be the development of life-cycle feeding programs for various classes of birds, rather than consideration of individual diets in isolation. Unfortunately, there is still a dearth of research information that views recommendations within the context of an overall program. With the sophistication we have today in our production systems, birds seldom fully recover from inappropriate nutrient intake at any time in their production cycle.

Because feed still represents 60 – 70% of the cost of production of most poultry products, there is a continual need to evaluate new or different sources of ingredients and to continually re-examine the more common ingredients. A yearly review of the published research data indicates that ingredient evaluation occupies the major portion of practical poultry nutrition research, and feed manufacturers should be aware of the potential of such new ingredients. Often, so-called new ingredients are not new in the sense of being novel to poultry feeding *per se*, rather they have not been as seriously considered in a particular geographical location. A

good example is the consideration of wheat as an ingredient in many areas of North America, whereas wheat has been a standard in other countries for 20-30 years. Under such conditions, feed manufacturers are encouraged to take a more global perspective on ingredient evaluation, because, for example, if wheat can be used successfully in Europe with strain A of broiler, in all likelihood it will be appropriate in another country assuming comparable conditions. Nutritionists must now have first-hand knowledge of production techniques to ensure that all conditions are comparable, as failure to do so is undoubtedly the reason for problems that periodically occur with such 'new' ingredients. In this context, justification of ingredient max/min constraints used during formulation is becoming more critical. As previously mentioned, the goals in many production situations vary commensurate with consumer demand for end products and/or manipulation of bird management. As such, nutritionists are now faced with an array of alternate programs dependent upon such specific, and often specialized, needs. The best example of this trend is nutritional modification aimed at manipulating meat or egg composition. Changing the proportion of energy:protein or amino acids or limiting feed intake during specific grow-out periods is known to influence fat deposition in the carcass. Likewise, choice of ingredients may well influence egg composition in relation to needs to improve human health. It is likely that nutritionists will be faced with increasing pressure from their customers, in terms of diets and programs aimed at meeting such market niches. In these situations, knowledge of ingredient profile and compatibility within a diet and feeding program become even more critical. A more holistic approach in the development of feeding programs will allow the poultry industry to pursue its goals of increased production, improved efficiency and increased specialization. It is hoped that the material provided in the following chapters will give the reader a background in developing such programs. Table 1.5 shows the expected number of birds that we will likely have to feed by 2006.

Table 1.5 Bird numbers (millions)

	1993	*2006*
BROILERS		
World	*30,700*	*46,000*
North America	*8,500*	*13,000*
South America	*3,700*	*7,500*
Europe	*6,600*	*6,600*
Asia	*9,700*	*18,000*
TURKEYS		
World	*580*	*700*
North America	*300*	*320*
South America	*20*	*40*
Europe	*230*	*280*
Asia	*25*	*30*
LAYERS		
World	*3,800*	*5,500*
North America	*480*	*600*
South America	*300*	*350*
Europe	*770*	*750*
Asia	*1,850*	*3,500*

1.5 Global Feed Production

The poultry industry accounts for 20–40% of animal feed use in most countries, and this proportion is invariably increasing over time. Table 1.6 shows estimates of feed production for broilers, turkeys, layers and associated breeders.

As a generalization, the numbers shown in Table 1.6 can be multiplied by 0.6 for an estimate of cereal needs and by 0.3 for needs of ingredients such as soybean meal. The feed industry will undoubtedly become more regulated and become part of any tracking initiatives introduced for eggs or meat. Regulation concerning the use and reconciliation for most drugs is now mandatory in many countries, through such programs as HACCP. Undoubtedly the cost of such extra regulation and control will be passed on to the poultry industry and eventually to the consumer.

Table 1.6 2006 Feed production (million tonnes)

	Broiler	*Broiler Breeder*	*Turkey*	*Turkey Breeder*	*Pullet*	*Layer*	*Total Poultry*
World	184	15	28	2.8	30	192	452
North America	52	4.2	7.9	0.8	8.4	54	127
South America	30	2.4	4.6	0.5	4.9	31	73
Europe	26	2.1	4.0	0.4	4.3	28	65
Asia	72	5.9	11.0	1.0	11.7	75	177

CHAPTER 2

INGREDIENT EVALUATION AND DIET FORMULATION

2.1 Description of Ingredients

1. Corn

Other Names: Maize

Nutritional Characteristics:

Corn has become the standard against which other cereals, cereal by-products and other energy-yielding ingredients are compared. In most poultry diets, corn will be the major contributor of metabolizable energy. World production is around 600 m tonnes of which 240 m tonnes are produced by the U.S.A. Although China is the world's second largest producer at around 100 m tonnes, Brazil at 40 m tonnes, is the second largest world exporter. The feed industry usually uses the equivalent of U.S.A. grade #2. As grade number increases, bulk density declines and there are greater permissible levels of damaged kernels and foreign matter allowed in the sample. Corn grade #2 should contain no more than 5% damaged kernels and 3% foreign material. While damaged kernels are unlikely to affect its energy value, foreign material is likely to reduce its energy value and hence monetary value. Broken kernels are also potential sites for mold infestation.

The energy value of corn is contributed by the starchy endosperm, which is composed mainly of amylopectin, and the germ, which contains most of the oil. Most corn samples contain 3 – 4% oil, although newer varieties are now available which contain up to 6 – 8% oil, and so contribute proportionally more energy. These high-oil corn varieties also contain 2 – 3% more protein, and proportionally more essential amino acids. The protein in corn is mainly as prolamin (zein) and as such, its amino acid profile is not ideal for poultry. This balance of amino acids, and their availability, must be seriously considered when low protein diets are formulated, because under these conditions the corn prolamin can contribute up to 50 – 60% of the diet protein. Corn is also quite high in

the yellow/orange pigments, usually containing around 5 ppm xanthophylls and 0.5 ppm carotenes. These pigments ensure that corn-fed birds will have a high degree of pigments in their body fat and in egg yolks.

While #2 grade is the standard for animal feeds, lower grades are often available due to adverse growing, harvesting or storage conditions. Dependent upon the reason for lower grade, the feeding value of corn usually declines with increase in grade number. Table 2.1 shows the metabolizable energy value of corn necessarily harvested at various stages of maturity due to adverse late-season growing conditions.

Table 2.1 Corn maturity and energy value

Corn description	*Moisture at harvest (%)*	*100 kernel wt at 10% moisture (g)*	*AMEn (kcal/kg) at 85% dry matter*
Very immature	*53*	*17*	*3014*
Immature	*45*	*22*	*3102*
Immature	*39*	*24*	*3155*
Mature	*31*	*26*	*3313*

The energy value of corn declines by 10 – 15 kcal/kg for each 1 lb reduction in bushel weight below the standard of 56 lb/bushel. However, these lower bushel weight samples show no consistent pattern with protein or levels of most amino acids, although there is an indication of loss of methionine content with the immature samples.

Another potential problem with handling immature, high-moisture corn is that the drying conditions must necessarily be harsher, or more prolonged in order to reduce moisture level to an acceptable 15%. Excessive or prolonged heating causes caramelization of corn which then has a characteristic smell and appearance, and there is concern that lysine will be less available because of Maillard Reaction with available carbohydrates.

As detailed in subsequent ingredients there is processing of corn that yields products such as gluten meal and corn oil. However, in North America well over 95% of corn is used for animal feeds.

There is some debate regarding the ideal size of ground corn particles for various classes of poultry. Within reason, the finer the grind, the better the pellet quality, while in mash diets, too fine a grind can lead to partial feed refusal. Table 2.2 indicates guidelines for expected distribution of particle sizes of corn ground to be 'fine' vs. 'coarse'. There seems to be some benefits in terms of AMEn of using a finer grind for birds up to 3 weeks of age, while a coarse grind is better for birds >21 d of age.

Depending upon the growing season and storage conditions, molds and associated mycotoxins can be a problem. Aflatoxin contamination is common with insect damaged corn grown in hot humid areas, and there is little that can be done to rectify the horrendous consequences of high levels of this mycotoxin. There is an indication of aluminosilicates partially alleviating the effects of more moderate levels of aflatoxin. If aflatoxin is even suspected as being a problem, corn samples should be screened prior to

blending and mixing. Zearalenone is another mycotoxin that periodically occurs in corn. Because the toxin ties up vitamin D_3, skeletal and eggshell problems can occur. With moderate levels of contamination, water-soluble D_3 via the drinking water has proven beneficial.

Mold growth can be a serious problem in corn that is transported for any length of time.

With corn shipped at □16% moisture and subjected to □25°C during shipping, mold growth often occurs. One solution to the problem is to add organic acids to the corn during loading for shipments. However, it must be remembered that while organic acids will kill molds, and prevent re-infestation, they have no effect on any mycotoxins already produced.

Table 2.2 Particle size distribution of corn (%)

Particle size (microns)	*Grind*	
	Fine	*Coarse*
<150	*5*	*<1*
300	*11*	*2*
450	*16*	*3*
600	*17*	*3*
850	*22*	*4*
1000	*16*	*4*
1500	*10*	*5*
2000	*1*	*10*
2500	*<1*	*24*
>3000	*<1*	*44*

Damaged kernels and foreign material are going to reduce the economic value of corn. However, Dale and co-workers at Georgia suggest the energy value of these contaminants is little different from whole corn. Broken kernels were just 200 kcal/kg lower than the AMEn of corn, while foreign material tested 600 kcal/kg lower than corn. Therefore having #4 grade corn with 10% damaged kernels and 5% foreign material vs 5% and 3% respectively for #2 grade, relates to a reduction of just 25 kcal/kg for this #4 vs #2 grade corn.

If corn is to be fed in mash diets, then there seems to be an advantage to grind to as uniform a particle size as possible, (0.7 – 0.9 mm). This size is often referred to as 'medium' grind. Birds fed fine or coarse-ground corn seem to exhibit lower digestibility values. Corn presents some problems to the manufacture of pelleted diets, and often good pellet durability in diets containing □30% corn can only be obtained by inclusion of pellet-binders.

Nutrient Profile: (%)

Dry Matter	85.0	*Methionine*	0.20
Crude Protein	8.5	*Methionine + Cystine*	0.31
Metabolizable Energy:		*Lysine*	0.20
(kcal/kg)	3330	*Tryptophan*	0.10
(MJ/kg)	13.80	*Threonine*	0.41
Calcium	0.01	*Arginine*	0.39
Av. Phosphorus	0.13		
Sodium	0.05	*Dig Methionine*	0.18
Chloride	0.05	*Dig Meth + Cys*	0.27
Potassium	0.38	*Dig Lysine*	0.16
Selenium (ppm)	0.04	*Dig Tryptophan*	0.07
Fat	3.8	*Dig Threonine*	0.33
Linoleic acid	1.9	*Dig Arginine*	0.35
Crude Fiber	2.5		

Bulk Density:

		kg/m^3	lb/ft^3	lb/bushel
Whole kernels	#2	696	42.2	54
	#4	632	38.3	49
Ground corn		642	40.0	51
Corn screenings		475	30.1	39

Formulation Constraints:

Bird age	*Min.*	*Max.*	*Comments*
0-4 wk	-	60%	*Usually no problems with upper limits. From 0-7d, birds may not digest as well as adult birds.*
4-18 wk	-	70%	
Adult layer	-	70%	*Higher levels cause more problems with pellet durability.*

QA Schedule:

Moisture	*CP*	*Fat*	*Ca/P*	*AA's*	*Other*
All deliveries	Wkly	6 mos	12 mos	12 mos	Molds – mycotoxins, AME,12 mos[1]

[1] *Assay to be conducted within 30 d of yearly harvest.*

2. Wheat

Nutritional Characteristics:

Wheat is commonly used in many countries as the major energy source in poultry diets. There is often confusion regarding the exact type of wheat being used, because wheats are described in a number of different ways. Traditionally wheats were described as being winter or spring varieties and these were usually grown in different regions because of prevailing climate and soil conditions. Wheats are sometimes also referred to as white or red, depending upon seed coat color, and finally there is the classification of hard vs soft. In the past, most winter wheats were white and soft, while spring wheats were hard and red. In terms of feeding value, the main criterion is whether wheat is soft or hard, because this will have an effect on composition, and especially on protein. Because of developments in plant breeding, the seed color and time of planting can now be more variable. Hard wheats have a greater proportion of protein associated with the starch and so contain more protein that is also higher in lysine. The proteins in hard wheat are useful in bread making, while the soft wheats are more useful in manufacture of cookies and cakes. Durum wheat used in manufacture of pasta is a very hard wheat. The physical hardness of these wheats is due to the strong binding between starch and the more abundant protein.

Varietal differences based on 'hard' vs 'soft' varieties seem to have inconsistent effects on AME and amino acid digestibility. A more consistent varietal effect is seen when genes from rye are translocated into wheat ostensibly to improve baking characteristics. These translocated wheat varieties (often termed 1B → 1R) have 10% lower amino acid digestibility and in the case of lysine, the differences may be as much as 18% in favor of the non-translocated varieties.

As with corn, the grading system for wheat relates to bulk density and the proportion of broken grains and foreign material. For #2 grade there is a maximum allowable inclusion of 5% foreign material and broken kernels. Feed grade wheat can have over 20% broken kernels and foreign material.

The composition of wheat is usually more variable than that of other cereals. Even within the hard wheats, protein level can vary from 10 to 18%, and this may relate to varietal differences and variance in growing conditions. Most hard wheats will not have to be dried after harvest, although drying conditions and moisture content of wheat at harvest appear to have little effect on feeding value. Environmental temperature during growing seems to have a major effect on wheat nitrogen content, and although high temperature can result in 100% increase in nitrogen level, the relative proportion of both lysine and starch tend to be decreased.

Depending upon the growing region, frost damaged or sprouted wheat is sometimes available to the feed industry. Frost damage effectively stops starch synthesis, and so kernels are small and shrunken. While 100 kernel weight should be around 27 g, with severe frost damage, this can be reduced to 14 – 16 g. As expected, the metabolizable energy level of this damaged wheat is reduced and under these conditions, there is a very good correlation between bulk density and metabolizable energy. For non-frosted wheat, however, there does not seem to be the same relationship between energy level and density.

Wheat will sometimes sprout in the field. Sprouted wheat would probably be rejected

simply based on appearance, although research data suggests that metabolizable energy level is only reduced by 3 - 5%. There are no problems in feeding sprouted wheat, as long as it has been dried to □ 14% moisture, and can be economical if discounted accordingly. Wheat contaminated with 'rust' however seems to more seriously affect feeding value, and metabolizable energy value can be reduced by up to 25%.

While wheats are much higher in protein content compared to corn, and provide only slightly less energy, there are some potential problems from feeding much more than 30% in a diet, especially for young birds. Wheat contains about 5 – 8% of pentosans, which can cause problems with digesta viscosity, leading to reduced overall diet digestibility and also wet manure. The major pentosan components are arabinoxylans, which are linked to other cell wall constituents, and these are able to adsorb up to 10 times their weight in water. Unfortunately, birds do not produce adequate quantities of xylanase enzymes, and so these polymers increase the viscosity of the digesta. The 10 - 15% reduction in ME of wheats seen with most young birds (<10 d age) likely relates to their inability to handle these pentosans. Variability in pentosan content of wheats *per se* likely accounts for most of the variability of results seen in wheat feeding studies, together with our inability to predict feeding value based on simple proximate analyses. These adverse effects on digesta viscosity seem to decrease with increased storage time for wheats. Problems with digesta viscosity can be controlled to some extent by limiting the quantity of wheat used, especially for young birds, and/or by using exogenous xylanase enzymes (see Section 2.3 g).

Wheats also contain α-amylase inhibitors. Although these inhibitors have not been fully identified, they are thought to be albumin proteins found predominantly in the endosperm. These inhibitors can apparently be destroyed by the relatively mild temperatures employed during pelleting. Compared to corn, wheat is also very low in levels of available biotin. Whereas it is sometimes difficult to induce signs of biotin deficiency in birds fed corn diets devoid of synthetic biotin, problems soon develop if wheat is the major cereal. While newly hatched chicks have liver biotin levels of around 3,000 ng/g, this number declines to 600 ng/g within 14 d in the wheat fed bird. Adding just 50 µg biotin/kg diet almost doubles the liver biotin reserve, while adding 300 µg/kg brings levels back to that seen in the day-old chick. There is also concern that wheat causes a higher incidence of necrotic enteritis in broiler chicks. It seems as though wheat provides a more suitable medium for the proliferation of certain pathogenic bacteria. The problem is most severe when wheat is finely ground, and incidence of necrotic enteritis can be tempered by grinding wheat through a roller mill rather than a hammer mill. Fine grinding of wheat can also cause beak impaction in young birds. The proteins in wheat tend to be 'sticky', and so adhere to the beak and mouth lining of the bird. Severe beak impaction tends to reduce feeding activity, increase feed deposited in open bell drinkers, and provides a medium in the mouth region that is ideal for bacterial and fungal growth. These problems can be resolved by coarse grinding of wheat.

Using wheat in diets for meat birds does however improve pellet durability. The same proteins that enhance the baking characteristics of hard wheats, also help to bind ingredients during pelleting. Adding □ 25% wheat to a diet has the same effect as including a pellet binder in diets that are difficult to pellet.

One advantage of wheat, is that it can be fed as whole grain to birds after 10 – 14 d of age. Offering whole wheat and a balancer feed with adequate minerals and vitamins provides a very economical way for farmers to utilize home-grown wheat. In recent studies we offered broilers a conventional three diet program, or after 7 d of age, a choice between whole wheat and crumbled broiler starter through to 49 d. From 7 – 21 d, male broilers voluntarily consumed about 15% of their ration as wheat, while from 21 – 35 d and 35 – 49 d this increased to 34% and 41% respectively. Table 2.3 shows performance data of these birds. Body weight was only slightly depressed, although carcass weight was significantly reduced and breast yield was reduced by about 10%. The free-choice wheat system did however show a saving of 10% in feed cost per kg liveweight gain although feed cost per kg of breast meat was not different. Another advantage claimed for feeding whole wheat to broilers is greater control over coccidiosis. Whole wheat feeding stimulates gizzard and gastric motility and the enhanced activity within this acidic environment is thought to reduce oocyte viability.

Potential Problems:

Wheats contain variable quantities of xylan, which is poorly digested and results in wet viscous excreta together with poor digestibility. As detailed in section 2.3g, this problem can be overcome by using synthetic xylanase enzymes. Feeding much more than 30% wheat can lead to beak/mouth impaction that can reduce feeding activity. Such material building-up in the mouth can be a site for mold and mycotoxin development. This problem can be resolved by grinding wheat more coarsely. With wheat as the major cereal, there is need for greater levels of supplemental biotin, since biotin availability in wheat has been reported to be as low as 0 – 15%.

Table 2.3 Broiler performance with free-choice wheat

Diet	*Body Wt 49d (g)*	*Feed:Gain*	*Protein Intake (g/kg Bwt)*	*Energy Intake (kcal/kg Bwt)*	*Carcass Wt (g)*
Control	*3030*	*1.93*	*370*	*6044*	*2230*[b]
Free-choice wheat	*2920*	*1.99*	*364*	*6106*	*2135*[a]

Adapted from Leeson and Caston, 1993

Nutrient Profile: (%)

Dry Matter	*87.0*	*Methionine*	*0.20*
Crude Protein	*12 - 15*	*Methionine + Cystine*	*0.41*
Metabolizable Energy:		*Lysine*	*0.49*
(kcal/kg)	*3150*	*Tryptophan*	*0.21*
(MJ/kg)	*13.18*	*Threonine*	*0.42*
Calcium	*0.05*	*Arginine*	*0.72*
Av. Phosphorus	*0.20*		
Sodium	*0.09*	*Dig Methionine*	*0.16*
Chloride	*0.08*	*Dig Meth + Cys*	*0.33*
Potassium	*0.52*	*Dig Lysine*	*0.40*
Selenium (ppm)	*0.50*	*Dig Tryptophan*	*0.17*
Fat	*1.5*	*Dig Threonine*	*0.32*
Linoleic acid	*0.50*	*Dig Arginine*	*0.56*
Crude Fiber	*2.70*		

Bulk Density:

		kg/m^3	lb/ft^3	lb/bushel
Whole kernels	*#2*	*738*	*46*	*57*
	Feed grade	*645*	*41*	*50*
Ground wheat		*530*	*33*	*42*

Formulation Constraints:

Bird age	***Min.***	***Max.***	***Comments***
0-4 wk	*15%*	*20 (40)[1]%*	*Minimum constraint used if improved pellet quality desired.*
4-18 wk	*15%*	*25 (50)%*	
Adult layer	*15%*	*25 (60)%*	*Maximum value in parenthesis if a synthetic xylanase used.*

[1] Higher inclusion level with enzymes.

QA Schedule:

Moisture	***CP***	***Fat***	***Ca/P***	***AA's***	***Other***
All deliveries	*Wkly*	*6 mos*	*12 mos*	*12 mos*	*Xylan, AME each 12 mos[1]*

[1] Assay to be conducted within 30 d of yearly harvest.

3. Milo

Other Names: sorghum, kaffir corn

Nutritional Characteristics:

In many characteristics, milo is almost comparable to corn in feeding value. There seem to be more varietal differences with sorghum, although on average, its energy value will be slightly less than that of corn. For those not wanting any marked degree of pigmentation of eggs or skin, milo offers the best high energy alternative to corn.

The feeding value of milo is essentially 95 – 96% that of corn, although in many markets it is priced at less than this. The starch in milo is intimately associated with the protein, and this leads to slightly reduced digestibility, especially in the absence of any heat processing. The major concern with milo, is the content of tannins, which are a group of polyphenols having the property of combining with various proteins. Birds fed tannins therefore exhibit reduced growth rate and in some instances increased incidence and severity of skeletal disorders. Hydrolyzable tannins are characterized by having a gallic acid unit combined by ester linkages to a central glucose moiety. Condensed tannins on the other hand are based on flavan-3-ols (catechin). Because tannins in milo are essentially condensed tannins, studies involving tannic acid (hydrolyzable) as a source of tannin may be of questionable value. The tannins are located in the outer seed coat and the underlying testa layer. Generally, the darker the seed coat, the higher the tannin content, although the tannins in the testa layer may be more indicative of general tannin content in the milo.

So-called bird resistant milos are usually very high in tannin, and are characterized by a darker seed coat color. These higher levels of tannin can result in up to 10% reduction of dry matter and amino acid digestibility. There is a good correlation between tannin content and AMEn, and as a generalization the following formula can be used:

AMEn = 3900 – 500 (% tannin), kcal/kg.

Tannins are most detrimental when fed to young birds, and especially when protein content of the diet is marginal. For example, it is usually recommended that milo with more than 1% tannin not be used for turkeys under 8 weeks of age. The relationship between tannins and diet protein or amino acids is not clear. Certainly feeding more protein or higher levels of certain amino acids seems to temper any growth retardation. The fact that methionine supplementation can overcome detrimental effects of tannins on growth rate, without alleviating problems with digestibility, suggests that birds can compensate for inferior digestibility by increasing their feed intake. Tannins also seem to increase the incidence of leg problems, especially in broiler chickens. The exact mechanism is unknown, although because bone mineral content is little affected, it is assumed to relate to derangement in the development of the organic matrix, especially in the region of the growth plate. There seems no advantage to increasing supplemental levels of any minerals or vitamins when high-tannin milos are necessarily used.

Various mechanisms have been tried to reduce the level or effect of tannins in milo. Unfortunately, most of these processes involve wet chemical treatment, which although quite simple, are expensive when re-drying of the milo is considered. Water treatment (25% with propionic acid for 10 d) has been shown to improve protein and energy availability by up to 10%. Alkali treatment seems the most effective means of reducing tannin levels, and products such as potassium and sodium hydroxide have both been used. Adding non-ionic polymers, such as polyethylene glycol also seems to be beneficial, while the problem of impaired bone development can be partially corrected by adding up to 0.8% available phosphorus to the diet of young birds.

Potential Problems:

The major potential problem is tannin content and so this antinutrient should be assayed routinely. As described in section 2.2 j, seed coat color of milo can be used to give an indication of tannin content.

Nutrient Profile: (%)

Dry Matter	*85.0*	*Methionine*	*0.12*
Crude Protein	*9.0*	*Methionine + Cystine*	*0.29*
Metabolizable Energy:		*Lysine*	*0.31*
(kcal/kg)	*3250*	*Tryptophan*	*0.09*
(MJ/kg)	*13.60*	*Threonine*	*0.32*
Calcium	*0.05*	*Arginine*	*0.40*
Av. Phosphorus	*0.14*		
Sodium	*0.05*	*Dig Methionine*	*0.09*
Chloride	*0.07*	*Dig Meth + Cys*	*0.24*
Potassium	*0.32*	*Dig Lysine*	*0.23*
Selenium (ppm)	*0.04*	*Dig Tryptophan*	*0.06*
Fat	*2.50*	*Dig Threonine*	*0.24*
Linoleic acid	*1.00*	*Dig Arginine*	*0.28*
Crude Fiber	*2.70*		

Bulk Density:

	kg/m^3	*lb/ft^3*	*lb/bushel*
Whole seed	*560*	*35.0*	*44.8*
Ground seed	*545*	*34.0*	*43.5*

Formulation Constraints:

Bird age	Min.	Max.	Comments
0-4 wk	-	40%	Maximum inclusion level necessarily reduced with high tannin samples, especially for young birds (20% max).
4-18 wk	-	50%	
Adult layer	-	40%	

QA Schedule:

Moisture	CP	Fat	Ca/P	AA's	Other
All deliveries	Wkly	6 mos	12 mos	12 mos	Tannin, AME – each 12 mos or more often if seed color variable. AME after harvest.

4. Barley

Nutritional Characteristics:

Barley is a cereal with medium content of both energy and protein, and while it can be used in poultry feeds, most is used in swine diets. Young birds are less able to digest barley, although this may be a consequence of ß-glucan content, and so this effect may relate to variety and growing conditions. The protein content of barley is usually around 11 – 12%, although much higher levels to 14 – 16% are sometimes encountered. These high-protein varieties are often little changed in content of essential amino acids. The lysine content of barley, within the range of 10 – 14% CP, is described by the equation 0.13 +0.024 x %CP. The metabolizable energy level of barley is correlated with bulk density, and there is a strong negative correlation with fiber.

Barley contains moderate levels of trypsin inhibitor, whose mode of action relates to sequestering of arginine, although by far the major problem with barley is content of ß-glucan. Most varieties of barley will contain 4 – 7% ß-glucan, although with dry growing conditions that involve rapid maturation and early harvest, the content can increase to 12 – 15%. As previously described for wheat, the main problem of these ß-glucans is the bird's inability to digest the structure, resulting in the formation of a more viscous digesta. This increased viscosity slows the rate of mixing with digestive enzymes and also adversely affects the transport of digested nutrients to the absorptive mucosal surface. The rate of diffusion to the intestinal microvilli is a function of the thickness of the unstirred boundary layer, and this increases with increased digesta viscosity. Motility of the digesta will also indirectly affect the thickness of the unstirred boundary layer, which will also affect rate of absorption of all nutrients. The adverse effect of ß-glucan is most pronounced with nutrients such as fats and fat-soluble compounds. Adding synthetic ß-glucanase enzymes to diets containing more than 15 – 20% barley seems to resolve many of

these problems, the usual outward sign of which is wet litter. Unfortunately, the description of exogenous enzymes is not standardized, as neither is the standard for units of efficacy, and so it is often difficult to compare products on the basis of the concentration of specific enzymes. Early studies show that any product should provide at least 120 units ß-glucanase/kg diet.

Enzymes seem to be less efficacious as the birds get older. Our studies show slight improvement in energy value of high ß-glucan barley when enzymes are used in diets for adult birds, and that some enzymes actually cause reduction in energy value when used with low ß-glucan barley. With this low ß-glucan barley, the addition of ß-glucanase enzymes actually caused birds to be in severe negative nitrogen balance for the 3 d duration of the balance study. For younger birds however, the efficacy of ß-glucanase enzymes is well established and many nutritionists consider barley plus enzymes as being equivalent in feeding value to wheat. These values can be used as a basis for economic evaluation of enzymes. While ß-glucans are most often regarded as being problematic to birds, there seems to be one advantage to their inclusion in the diet. Feeding ß-glucans reduces blood cholesterol in birds, and this likely positive effect is reversed by use of synthetic ß-glucanases. The mode of action of ß-glucans may well be simply via sequestering of fats and bile acids in the digesta.

Barley can be used in choice-feeding studies, as previously described for wheat. Due to the physical structure of the kernel however, with its sharp spinets, birds are often reluctant to consume whole barley grain. Turkeys at least seem to readily eat whole barley in a choice-feeding situation after 50 d of age.

Potential Problems:

The moderate level of energy usually limits the inclusion of barley in most poultry diets. Additionally, the level of ß-glucan can be problematic in terms of poor performance and wet litter/manure. Synthetic enzymes can be used to overcome most of the problems.

Nutrient Profile: (%)

Dry Matter	*85.0*	*Methionine*	*0.21*
Crude Protein	*11.5*	*Methionine + Cystine*	*0.42*
Metabolizable Energy:		*Lysine*	*0.39*
(kcal/kg)	*2780*	*Tryptophan*	*0.19*
(MJ/kg)	*11.63*	*Threonine*	*0.40*
Calcium	*0.10*	*Arginine*	*0.51*
Av. Phosphorus	*0.20*	*Dig Methionine*	*0.16*
Sodium	*0.08*	*Dig Meth + Cys*	*0.32*
Chloride	*0.18*	*Dig Lysine*	*0.31*
Potassium	*0.48*	*Dig Tryptophan*	*0.15*
Selenium (ppm)	*0.30*	*Dig Threonine*	*0.29*
Fat	*2.10*	*Dig Arginine*	*0.41*
Linoleic acid	*0.80*		
Crude Fiber	*7.50*		

Bulk Density:

	kg/m^3	*lb/ft^3*	*lb/bushel*
Whole barley	674	42	53.8
Ground barley	417	26	33.3

Formulation Constraints:

Bird age	*Min.*	*Max.*	*Comments*
0-4 wk	-	*10 (30)%*[1]	*ß-glucan content usually dictates maximum inclusion level*
4-18 wk	-	*15 (40)%*	
Adult layer	-	*15 (30)%*	

[1] *with ß-glucanase enzyme*

QA Schedule:

Moisture	*CP*	*Fat*	*Ca/P*	*AA's*	*Other*
All deliveries	*Wkly*	*6 mos*	*12 mos*	*12 mos*	*AMEn*[1] *12 mos; ß-glucan, bulk density-monthly since correlates with AME*

[1] *within 30 d of yearly harvest.*

5. *Rice*

Nutritional Characteristics:

Almost without exception, rice is grown for human consumption, although periodically in rice growing areas, samples unfit for human consumption, or damaged samples are available for animal feeding. Rice is a relatively poor quality ingredient for poultry, containing only 7 – 8 % CP and providing just 2600 – 2700 kcal ME/kg. Rice does contain high levels of trypsin inhibitor that will be destroyed at normal pelleting temperatures. As detailed in the next section on cereal by-products, rice bran and rice polishings are more commonly used in poultry feeds than is rice grain itself.

Potential Problems:

Because most feed sources will have been graded as unfit for human consumption, then the reason for rejection should be ascertained. Mold growth and mycotoxin (aflatoxin) contamination are often the basis for such grading.

Nutrient Profile: (%)

Dry Matter	85.0	Methionine	0.12
Crude Protein	7.3	Methionine + Cystine	0.23
Metabolizable Energy:		Lysine	0.22
(kcal/kg)	2680	Tryptophan	0.11
(MJ/kg)	11.21	Threonine	0.34
Calcium	0.04	Arginine	0.62
Av. Phosphorus	0.13		
Sodium	0.03	Dig Methionine	0.09
Chloride	0.28	Dig Meth + Cys	0.15
Potassium	0.34	Dig Lysine	0.17
Selenium (ppm)	0.17	Dig Tryptophan	0.07
Fat	1.70	Dig Threonine	0.27
Linoleic acid	0.60	Dig Arginine	0.50
Crude Fiber	10.00		

Bulk Density:

	kg/m^3	lb/ft^3	lb/bushel
Whole kernels	722	45	57.6
Ground rice	626	39	49.9

Formulation Constraints:

Bird age	Min.	Max.	Comments
0-4 wk	-	15%	Maximum constraints due to low energy.
4-18 wk	-	25%	
Adult layer	-	20%	

QA Schedule:

Moisture	CP	Fat	Ca/P	AA's	Other
All deliveries	1 mos	1 mos	12 mos	12 mos	AME[1]

[1] within 30 d of yearly harvest.

6. Wheat by-products

Other Names: wheat shorts, wheat middlings, wheat bran, wheat millrun, wheat screenings

Nutritional Characteristics:

During the processes of cleaning wheat and subsequent manufacture of flour, up to 40% by weight is classified as by-product material. There is considerable variation in the classification and description of these by-products, and great care must be taken when formulating with wheat by-products in different countries. Traditionally there were three major by-products, namely wheat bran, wheat shorts and wheat middlings. Bran is the outer husk, and so is very high in fiber and rarely used in poultry diets. Unfortunately, in many countries the term wheat bran is used to describe wheat middlings. A check on crude fiber level of wheat by-products is necessary to ensure correct terminology. The finer material removed during bran extraction, was traditionally termed wheat shorts. As wheat is ground through a series of grinders of decreasing size, middlings are produced, most of which is extracted as flour. Wheat middlings are the major by-product from the final extraction of flour.

In the U.S.A., the term red-dog was sometimes used to describe the very fine material extracted from 'red' wheats, and was similar to shorts. Today most by-products are combined at the flour mills, and commonly called wheat shorts. The only other by-product produced in reasonable quantity is wheat screenings, which as its name implies, is material removed during initial cleaning and separation. If screenings are composed mainly of broken wheat kernels, then their nutritive value is little different to wheat.

Wheat by-products such as shorts can contain very high levels of 'natural' phytase enzyme. When more than 15% shorts are used in a diet this endogenous enzyme can be greater than levels of commercial phytase added to the diet, and so influence assay results. While endogenous phytase levels are high, it is questionable if this enzyme is beneficial to the bird at the pH of the proventriculus or small intestine.

Wheat shorts: Shorts are the major by-product of flour manufacture and since they are usually a composite of various fractions, nutrient profile can be variable. The major difference will be in the quantity of bran included in the material, and so this directly influences its energy value. If wheat shorts contain much more than 5% crude fiber, it is an indication of a greater proportion of bran-type residues. Dale (1996) suggests that the metabolizable energy value of wheat by-product is directly proportional to its fiber content, and that ME can be described as:

3182 – 161 x % crude fiber (kcal/kg)

With an average fiber value of 5%, ME is around 2370 kcal/kg. However, it is common to see a range of 3 to 10% CF depending upon flour manufacturing procedures, which equates to a range of ME values of from 1570 to 2700 kcal/kg. Measuring crude fiber level of wheat by-products is obviously important in quality assurance programs. As described previously with wheat, most by-products will contain xylan,

and so xylanase enzyme is advisable if inclusion levels are >15% for young birds or > 30% for birds after 4 weeks of age.

Wheat bran: The main characteristics are high fiber, low bulk density and low metabolizable energy. Bran is however, quite high in protein, and amino acid profile is comparable to that seen in whole wheat. Bran has been claimed to have a growth promoting effect for birds which is not directly related to any contribution of fiber to the diet. Such growth promotion is possibly derived from modification of the gut microflora. The energy value of bran may be improved by up to 10% by simple steam pelleting, while the availability of phosphorus is increased by up to 20% under similar conditions. Bran would only be considered where limits to growth rate are required, and where physical feed intake is not a problem. High bran diets promote excessive manure wetness, and transportation costs of bran diets are increased in proportion to the reduced bulk density of the diet.

Wheat screenings: Wheat screenings are a by-product of the cleaning and grading of wheat that itself is usually destined for human consumption. The product is therefore available in most countries that have significant wheat production. In addition to broken and cracked wheat kernels, screenings will also contain wild oats and buckwheat as well as weed seeds and other contaminants. The higher grades (#1 or #2) contain significant proportions of wheat, and so their nutrient profile is very similar to that of wheat. The weed seeds, depending upon variety, may be of some nutritional value. Since certain weed seeds produce a feed-refusal type reaction in layers, only the highest grades should be considered for high producing stock. The weed seeds can pose problems to arable farms that use manure from birds fed coarsely ground diets containing screenings, since some of the weed seeds can pass undamaged through the digestive tract. The level of screenings used in finisher diets of meat birds should also be severely limited, since breakage of the gut during processing leads to fine particles of black weed seeds adhering to the fat pads of the bird – such birds are easily recognized and often condemned due to fecal contamination. Number 1 and 2 grade screenings can be used up to 40% of the diet for broilers and layers.

Potential Problems:

The fiber content will directly influence energy value. With wheat screenings there will likely be some weed seeds present, and these may cause feed refusal.

Nutrient Profile: (%)

	Shorts	Screening	Bran		Shorts	Screenings	Bran
Dry Matter	90	90	90	Methionine	0.21	0.21	0.10
Crude Protein	15	15	16	Meth + Cyst	0.40	0.42	0.20
Metabolizable Energy:				Lysine	0.61	0.53	0.60
(kcal/kg)	2200	3000	1580	Tryptophan	0.21	0.20	0.31
(MJ/kg)	9.20	12.55	6.61	Threonine	0.50	0.42	0.34
Calcium	0.07	0.05	0.10	Arginine	0.80	0.60	0.85
Av. Phosphorus	0.30	0.20	0.65				
Sodium	0.07	0.08	0.06	Dig Methionine	0.16	0.15	0.08
Chloride	0.10	0.05	0.20	Dig Meth + Cys	0.30	0.32	0.15
Potassium	0.84	0.55	1.20	Dig Lysine	0.48	0.39	0.42
Selenium (ppm)	0.80	0.57	0.92	Dig Tryptophan	0.15	0.15	0.24
Fat	4.0	4.1	4.5	Dig Threonine	0.41	0.31	0.28
Linoleic acid	1.6	0.7	1.7	Dig Arginine	0.71	0.52	0.79
Crude Fiber	5.0	3.0	12.0				

Bulk Density:

	kg/m^3	lb/ft^3	lb/bushel
Wheat bran	193	12	15.4
Wheat shorts	480	30	38.4
Wheat screenings	740	46	58.9

Formulation Constraints:

	Bird age	Min.	Max.	Comments
Shorts, and Screenings	0-4 wk		10%	20%Minimum if pellet durability an issue
	4-18 wk		30%	
	Adult layer		30%	
Bran	4 wk+		10%	Energy will be the limiting factor

QA Schedule:

Moisture	CP	Fat	Ca/P	AA's	Other
All deliveries	Wkly	6 mos	12 mos	12 mos	Crude fiber on all deliveries. AMEn yearly

7. Bakery meal

Other Names: Cookie meal, bread meal
Nutritional Characteristics:

Bakery meal is a by-product from a range of food processing industries. In order to ensure consistent composition, individual products must be blended or the supplier large enough to provide adequate quantities from a single manufacturing process. The most common by-products come from bread and pasta manufacture, as well as cookies and snack foods. By-products from snack foods can be quite high in salt and fat. Bakery meal is often derived from pre-cooked products and so digestibility is often higher than for the original starch components.

Fillers are sometimes used to improve flow characteristics of high-fat bakery meals. The most-common fillers are soybean hulls and limestone which influence nutritive value accordingly. The metabolizable energy value of bakery meal can be described as:

4000 – (100 x % fiber + 25 x % ash) kcal/kg $\therefore$ with 4% fiber and 3% ash, ME becomes 3525 kcal/kg

Potential Problems:

Quality control programs must ensure consistent levels of sodium, fiber and ash.

Nutrient Profile: (%)

Dry Matter	*90.0*	*Methionine*	*0.21*
Crude Protein	*10.5*	*Methionine + Cystine*	*0.40*
Metabolizable Energy:		*Lysine*	*0.29*
(kcal/kg)	*3500*	*Tryptophan*	*0.13*
(MJ/kg)	*14.6*	*Threonine*	*0.30*
Calcium	*0.05*	*Arginine*	*0.50*
Av. Phosphorus	*0.13*		
Sodium	*0.50*	*Dig Methionine*	*0.18*
Chloride	*0.48*	*Dig Meth + Cys*	*0.34*
Potassium	*0.62*	*Dig Lysine*	*0.19*
Selenium (ppm)	*0.30*	*Dig Tryptophan*	*0.08*
Fat	*9.5*	*Dig Threonine*	*0.21*
Linoleic acid	*3.0*	*Dig Arginine*	*0.40*
Crude Fiber	*2.5*		

Bulk Density:

kg/m^3	lb/ft^3	lb/bushel
353	22.0	28.0

Formulation Constraints:

Bird age	*Min.*	*Max.*	*Comments*
0-4 wk		*10%*	*Concern over sodium content*
4-18 wk		*15%*	
Adult layer		*15%*	

QA Schedule:

Moisture	*CP*	*Fat*	*Ca/P*	*AA's*	*Other*
All deliveries	*1 mos*	*1 mos*	*6 mos*	*12 mos*	*Na content of all samples if snack foods part of bakery meal*

8. Rice by-products

Other Names: Rice bran, rice polishings, rice pollards
Nutritional Characteristics:

Rice by-products are the result of dehulling and cleaning of brown rice, necessary for the production of white rice as a human food. Rice by-products are one of the most common cereal by-products available to the feed industry, with world production estimated at around 45 m tonnes. The by-product of preparing white rice, yields a product called rice bran, which itself is composed of about 30% by weight of rice polishings and 70% true bran. In some regions, the two products are separated, being termed polishings and bran. Alternatively, the mixture is sometimes called rice bran, whereas in other areas the mixture may be called rice pollards. The polishings are very high in fat content and low in fiber while the true bran is low in fat and high in fiber. The proportions of polishings and true bran in a mixed product will therefore have a major effect on its nutritive value. In the following discussion, rice bran refers to the mixture of polishings and bran. The composition of any sample of mixed rice bran can be calculated based on levels of fat vs fiber.

Because of a high oil content (6 – 10%) rice bran is very susceptible to oxidative rancidity. Raw bran held at moderate temperatures for 10 – 12 weeks can be expected to contain 75 – 80% of its fat as free fatty acids, which are themselves more prone to rancidity. Rice bran should be stabilized with products such as ethoxyquin. Higher levels of ethoxyquin give greater protection against rancidity although economical levels appear to be around 250 ppm. Rice bran can also be stabilized by heat treatment. Extrusion at 130ºC greatly reduces chances of rancidity, and of the development of free fatty acids.

When high levels of raw rice bran are used (□ 40%) there is often growth depression and reduction in feed efficiency, likely associated with the presence of trypsin inhibitor and high levels of phytic acid. The trypsin inhibitor, which seems to be a relatively low molecular weight structure, is destroyed by moist heat, although phytic acid is immune to this process. The phosphorus content of rice bran is assumed to be only 10%

available for very young birds. However, phosphorus availability may increase with age, and if this happens, it could create an imbalance of calcium:phosphorus. This latter effect is suggested as the reason for improved growth response in older birds fed rice bran when extra calcium is added to the diet. Phytase enzyme can be used to advantage in diets containing > 15% rice bran. Because of the potential for high fiber content, use of rice bran may be improved with addition of exogenous arabinoxylanase enzymes.

Potential Problems:

Rice bran should be stabilized with an antioxidant if storage at the mill is to be longer than a few weeks. Heating is advisable if young birds (< 3 weeks) are fed > 10% rice bran, to limit adverse effects of trypsin inhibitor.

Nutrient Profile: (%)

	Bran	*Polishing*		*Bran*	*Polishing*
Dry Matter	*90.0*	*90.0*	*Methionine*	*0.29*	*0.21*
Crude Protein	*13.0*	*11.0*	*Methionine + Cystine*	*0.30*	*0.52*
Metabolizable Energy:			*Lysine*	*0.51*	*0.50*
(kcal/kg)	*1900*	*2750*	*Tryptophan*	*0.18*	*0.12*
(MJ/kg)	*7.95*	*11.52*	*Threonine*	*0.38*	*0.32*
Calcium	*0.06*	*0.06*	*Arginine*	*0.52*	*0.61*
Av. Phosphorus	*0.80*	*0.18*			
Sodium	*0.10*	*0.10*	*Dig Methionine*	*0.15*	*0.16*
Chloride	*0.17*	*0.17*	*Dig Meth + Cys*	*0.22*	*0.24*
Potassium	*1.30*	*1.17*	*Dig Lysine*	*0.39*	*0.41*
Selenium (ppm)	*0.19*	*0.17*	*Dig Tryptophan*	*0.13*	*0.08*
Fat	*5.0*	*15.0*	*Dig Threonine*	*0.28*	*0.25*
Linoleic acid	*3.4*	*6.2*	*Dig Arginine*	*0.40*	*0.48*
Crude Fiber	*12.0*	*2.5*			

Bulk Density:

	kg/m³	*lb/ft³*	*lb/bushel*
Rice bran	*417*	*26*	*33*
Rice polishings	*480*	*30*	*38*

Formulation Constraints:

Bird age	*Min.*	*Max.*	*Comments*
0-4 wk		*10%*	*Fat rancidity the major concern*
4-8 wk		*20%*	*High phytate content*
Adult		*25%*	

QA Schedule:

Moisture	*CP*	*Fat*	*Ca/P*	*AA's*	*Other*
All deliveries	*monthly*	*All deliveries*	*6 mos*	*12 mos*	*Fiber for all deliveries*

9. Soybean meal

Other Names: High protein SBM
Nutritional Characteristics:

Soybean meal has become the worldwide standard against which other protein sources are compared. Its amino acid profile is excellent for most types of poultry, and when combined with corn or sorghum, methionine is usually the only limiting amino acid.

The protein level in soybean meal can be variable, and this may be a reflection of seed variety and/or processing conditions involved in fat extraction. Traditionally the higher protein meals are produced from de-hulled beans, whereas the lower protein (44% CP) meals invariably contain the seed hulls, and are higher in fiber and lower in metabolizable energy. There is some variation in seed type used and this can affect protein and fat content, which are negatively correlated. Whereas fat content of the seed is dictated early in seed development, protein is deposited through to the end of maturity, and therefore growing and harvesting conditions tend to have more of an effect on protein content of the seed. For soybean processors, about 65% of the value of soybeans is attributed to their protein content, and 35% to the oil. In recent years, there have been a number of 'new' varieties introduced, and some of these are produced by genetic engineering. At this time (2004) there are no new GMO products modified in terms of enhanced nutrient profile or reduced anti-nutritional content. Current GMO soybeans are modified for agronomic reasons, and there is no indication that they have different feeding value. In the future, there seems great potential for reduction in content of anti-nutrients within GMO soybeans.

Soybeans have to be heat-treated in order to inactivate various anti-nutrients. During processing, soybeans are dehulled (about 4% by weight) and then cracked prior to conditioning at 70ºC. The hot cracked beans are then flaked to about 0.25 mm thickness to enhance oil extraction by a solvent, which is usually hexane. Hexane must be removed from the meal because it is a highly combustible material and a potent carcinogen. Problems occurring during processing that result in residual hexane in the meal are usually noticed by severe and sudden liver failure in birds. Soybean meals tend to be very dusty, and in mash diets, soy is responsible for some of the dust found in controlled environment poultry houses. Soybean meal is also notorious for its poor flow characteristics and for bridging in storage bins. Addition of products such as bentonite clays, even at levels as low as 2.5 kg/tonne, can greatly improve the flow characteristics of soybean meal.

Soybeans contain a number of natural toxins for poultry, the most problematic being trypsin inhibitor. As with most types of beans, the trypsin inhibitors will disrupt protein digestion, and their presence is characterized by compensatory hypertrophy of the pancreas. Apart from reduced growth rate and egg production, presence of inhibitors is therefore diagnosed by a 50-100% increase in size of the pancreas. Fortunately, the heat treatment employed during processing is usually adequate to destroy trypsin inhibitors and other less important toxins such as hemaglutinins (lectins). In developing countries, trypsin inhibitor levels are sometimes controlled by fermentation or germinating beans, where after 48 hrs of treatment, protein digestibility is almost equivalent to that seen in conventionally heated beans. Trypsin inhibitor levels are usually 'assayed' indirectly by measuring urease activity in processed soybean meal. Urease is of little consequence to the bird, although the heat-sensitivity characteristics of urease are similar to those of trypsin inhibitors, and urease levels are much easier to measure. Residual urease in soybean meal has therefore become the standard in quality control programs. Urease is assessed in terms of change in pH during the assay, where acceptance values range between 0.05 and 0.15. Higher values mean there is still residual urease (trypsin inhibitor) and so the test is useful to indicate undercooked meal. However, while low values mean that the proteases have been destroyed, there is no indication of potential overcooking, which can destroy lysine and reduce ME value. For this reason other tests are sometimes used. A fairly easy test to accomplish is protein solubility in potassium hydroxide. Dale and co-workers at the University of Georgia have shown a good correlation between the amount of protein soluble in 2% KOH, and chick growth, determined in a bioassay. Heating tends to make the protein less soluble, and so high values suggest undercooking, while low values mean overcooking. Values of □ 85% solubility indicate under-processing and □ 70% mean the sample has been over-processed. The assay is influenced by particle size of soybean meal and time of reaction, and so these must be standardized within a laboratory. As soybean meal is heated, its color changes and again this can be used in quality control programs. Simply measuring color in a Hunterlab Color Spectrophotometer can indicate degree of cooking. Degrees of 'lightness', 'redness' and 'yellowness' can be measured since these change with cooking temperature and time. Again it is important to control particle size during this assay.

Discussion about soybean meal quality invariably involves the significance of trypsin inhibitor relative to other antinutrients. It is often claimed that only about 50% of the growth depression resulting from consumption of under-heated soybean meal is due to active trypsin inhibitor. The other antinutrients of importance are isoflavones, lectins and oligosaccharides. Lectins are antinutritional glycoproteins that bind to the intestinal epithelium resulting in impaired brush border function. Such 'thickening' of the epithelium results in reduced efficiency of absorption. There are strains of soybeans that contain no lectins, and so studying their feeding value provides some information on importance or not of lectins. Feeding uncooked lectin-free soybean meal produces greater broiler growth than does feeding regular uncooked soybean. However, the growth is still less than using trypsin inhibitor-free soybeans. These data support the concept that lectins are much less important than are trypsin inhibitors in assessing nutritive value of soybean meal.

While undercooking of soybean meal is the most common result of incorrect processing, overheating sometimes occurs. It seems as though lysine availability is most affected by overcooking of soybeans, since addition of other amino acids rarely corrects growth depression seen in birds fed such meals. When soybeans are overcooked, KOH protein solubility declines. Using data from Dale and co-workers, it seems as though problems of using overheated soybean meal can be resolved by adding 0.5 kg L-Lysine HCl/tonne feed for each 10% reduction in protein solubility below a value of 70%.

Over the last few years there has been growing concern about some of the less digestible carbohydrates in soybean meal. The α-galactoside family of oligosaccharides cause a reduction in metabolizable energy with reduced fiber digestion and quicker digesta transit time. Birds do not have an α1:6 galactosidase enzyme in the intestinal mucosa. Apart from reduced digestibility, there is concern about the consistency of excreta and its involvement in foot-pad lesions in both young turkeys and broiler breeders. Soybean meal usually contains about 6% sucrose, 1% raffinose and 5% stachyose, all of which are poorly digested by the bird. Adding raffinose and stachyose to isolated soybean protein to mimic levels seen in soybean meal, causes a significant reduction in metabolizable energy. These problems limit the diet inclusion level of soybean meal, especially in turkey prestarters. The solution to the problem relates to change in soybean processing conditions or use of exogenous feed enzymes. Extracting soybeans with ethanol, rather than hexane, removes most of the oligosaccharides. The metabolizable energy value of soybean meal extracted from low oligosaccharide varieties of soybeans is increased by about 200 kcal/kg. There are now some galactosidase enzyme products available which are designed specifically to aid digestion of vegetable proteins and presumably these help in digestion of products such as raffinose and stachyose.

Potential Problems:

In most feeding situations, the main concern is usually processing conditions and knowledge of urease index or protein solubility. Soybean meal is also very high in potassium. In regions where animal proteins are not used, then necessarily high levels of soybean meal can lead to enteritis, wet litter, and food pad lesions.

Nutrient Profile: (%)

Dry Matter	*90.0*	*Methionine*	*0.72*
Crude Protein	*48.0*	*Methionine + Cystine*	*1.51*
Metabolizable Energy:		*Lysine*	*3.22*
(kcal/kg)	*2550*	*Tryptophan*	*0.71*
(MJ/kg)	*10.67*	*Threonine*	*1.96*
Calcium	*0.20*	*Arginine*	*3.60*
Av. Phosphorus	*0.37*		
Sodium	*0.05*	*Dig Methionine*	*0.64*
Chloride	*0.05*	*Dig Meth + Cys*	*1.27*
Potassium	*2.55*	*Dig Lysine*	*2.87*
Selenium (ppm)	*0.11*	*Dig Tryptophan*	*0.53*
Fat	*0.5*	*Dig Threonine*	*1.75*
Linoleic acid	*0.3*	*Dig Arginine*	*3.20*
Crude Fiber	*3.0*		

Bulk Density:

kg/m³	***lb/ft³***	***lb/bushel***
640	*40*	*51.5*

Formulation Constraints:

Bird age	***Min.***	***Max.***	***Comments***
0-4 wk		*30%*	*Higher levels may lead to wet litter due to high K intake*
4-8 wk		*30%*	
Adult		*30%*	

QA Schedule:

Moisture	***CP***	***Fat***	***Ca/P***	***AA's***	***Other***
All deliveries	*All deliveries*	*6 mos*	*12 mos*	*12 mos*	*Urease or KOH solubility each 6 mos, AMEn each 12 mos*

10. Soybeans

Other Names: Full-fat soybeans

Nutritional Characteristics:

Soybeans provide an excellent source of both energy and protein for poultry. As with any ingredient, their usage rate depends upon economics, although in the case of soybeans such economics relate to the relative price of soybean meal and of supplemental fats. Soybeans contain about 38% crude protein, and around 20% oil.

Comparable to the manufacture of soybean meal, soybeans must be heat processed in some way to destroy the trypsin inhibitors and to improve overall protein digestibility. Feeding raw soybeans or improperly processed soybeans will cause poor growth rate or reduced egg production and egg size. If processing conditions are suspect, the birds' pancreas should be examined, because if trypsin inhibitors are still present pancreas size can be expected to increase by 50-100%. While processed beans should be periodically tested for trypsin inhibitor or urease levels, a simple on-going test is to taste the beans. Under-heated beans have a characteristic 'nutty' taste, while over-heated beans have a much darker color and a burnt taste. The problem with overheating is potential destruction of lysine and other heat-sensitive amino acids.

Heat-treated soybeans can be easily ground in a hammer mill, even though they are high in fat, and the ground product is a relatively free-flowing material. Because of the high oil content, ground beans should not be stored for any length of time due to potential for oxidative rancidity. However, it is important that beans be well ground because it is necessary to release fat from the plant cells in order to aid digestion. Coarsely ground beans have lower fat digestibility than do more finely ground material. Heating beans by whatever means usually results in considerable 'shrinkage' which is mainly due to loss of water. In many situations, shrinkage will be up to 7%, but of this, less than 1% will be real loss of dry matter.

Recently there has been growing interest in processing beans through extruders or expanders. The heat necessary to destroy trypsin inhibitors and other hemagglutinins found in raw beans is dependent upon exposure time, and so high temperatures for a shorter time period are as effective as lower temperatures for longer times. Because both expanders and extruders are fast throughput, the beans have a relatively short dwell time in the conditioning chamber. Consequently, slightly higher temperatures are necessary, and depending upon design, such machines are best operated at 140-155ºC. Again, the effectiveness of expanding and extrusion can be measured by tests for urease and available lysine content.

Potential Problems:

Under-heating of soybeans is detected as a high urease or KOH protein solubility. If broiler finisher diets contain > 30% soybeans, then their body fat will become less saturated and more prone to oxidative rancidity. This latter problem can be resolved to some extent by using higher levels of vitamin E (75-100 IU/kg).

Nutrient Profile: (%)

Dry Matter	*90.0*	*Methionine*	*0.49*
Crude Protein	*38.0*	*Methionine + Cystine*	*1.12*
Metabolizable Energy:		*Lysine*	*2.41*
(kcal/kg)	*3880*	*Tryptophan*	*0.49*
(MJ/kg)	*16.23*	*Threonine*	*1.53*
Calcium	*0.15*	*Arginine*	*2.74*
Av. Phosphorus	*0.28*		
Sodium	*0.05*	*Dig Methionine*	*0.41*
Chloride	*0.04*	*Dig Meth + Cys*	*0.93*
Potassium	*1.50*	*Dig Lysine*	*2.00*
Selenium (ppm)	*0.10*	*Dig Tryptophan*	*0.39*
Fat	*20.0*	*Dig Threonine*	*1.27*
Linoleic acid	*9.0*	*Dig Arginine*	*2.31*
Crude Fiber	*2.0*		

Bulk Density:

kg/m³	***lb/ft³***	***lb/bushel***
750	*47*	*60*

Formulation Constraints:

Bird age	***Min.***	***Max.***	***Comments***
0-4 wk		*15*	*In broiler finisher diets, > 30% may cause 'oily' fat depots.*
4-8 wk		*20*	
Adult		*30*	

QA Schedule:

Moisture	***CP***	***Fat***	***Ca/P***	***AA's***	***Other***
All deliveries	*1 mos*	*1 mos*	*6 mos*	*12 mos*	*Monthly analyses for urease or KOH solubility*

11. Canola meal

Nutritional Characteristics:

Canola is a widely grown crop in western Canada and production is increasing in other parts of the world. Production has been influenced by the marked increase in the demand for canola oil as well as the ability of this high protein oilseed to grow in northern climates where the short growing season is not suitable for the production of soybeans.

While canola was derived from varieties of rapeseed, its composition has been altered through genetic selection. The level of goitrogens and erucic acid, two of the more detrimental constituents of the original rapeseed cultivars, have been markedly reduced. Erucic acid levels are now negligible while goitrogen levels are down to less than 20 μg/g and these levels are low enough to be of little or no problem to poultry. Varieties containing such levels of toxins are classified as canola and are often referred to as 'double zero varieties'.

Canola still has enough goitrogen activity to result in measurable increases in thyroid weight, although this does not appear to be a problem affecting the performance of poultry. The tannin levels in canola can also be relatively high, with up to 3% for some cultivars. Again, research has shown that the canola tannins have little influence in the utilization of the protein in diets containing appreciable levels of the meal.

Canola meal also contains significant quantities (1.5%) of sinapine. While this compound poses no problem to most classes of poultry, a significant percent of brown egg layers produce eggs with a fishy and offensive odour when fed canola sinapines. One of the end products of the degradation of sinapine in the intestinal tract is trimethylamine and it is this compound, which is involved in the production of fishy- flavored eggs. A small proportion of today's brown egg laying birds lack the ability to produce trimethylamine oxidase which effectively breaks down the compound and so the intact trimethylamine is deposited into the egg. Even 1% sinapine in canola can result in off-flavored eggs. It should be pointed out that brown eggs produced by broiler breeders, are not affected by canola sinapines.

While canola meal has been accepted by the feed industry as a high quality feedstuff for poultry, there continues to be isolated reports of increased leg problems with broilers and turkeys, smaller egg size with layers and in some cases, reports of increased liver hemorrhages when diets contain significant amounts of canola meal. There are several reports which suggest that increased leg problems resulting from feeding canola may be due to its having a different mineral balance than does soybean meal. The addition of dietary K, Na and in some cases Cl have, under certain conditions, altered bird performance. Canola is also high in phytic acid and so there is speculation that the high level of this compound may be sequestering zinc and this affects bone development. The smaller egg size reported with canola meal diets seems to be a direct result of lower feed intake. Canola meal levels should therefore be limited in diets for very young laying hens, or at least until feed intake plateaus at acceptable levels.

Within the past few years, there have been reports suggesting that high levels of sulfur in canola meal may be responsible for some of the leg problems and reduced feed intake noted with canola meal diets. Canola meal contains 1.4% sulfur while soybean meal contains around 0.44%.

Up to 75% of the sulfur in soybean meal is contributed by the sulfur amino acids compared to around only 20% for canola meal. High levels of dietary sulfur have been reported to complex intestinal calcium and lead to increased calcium excretion. This could explain the reports suggesting low availability of calcium in canola meal, and so possibly contribute to more leg problems. While lower weight gain has periodically been reported with canola diets, it is usually noted that feed:gain ratios are little affected. This situation suggests that the reduction in gain was not the result of reduced nutrient availability but rather a direct effect on appetite, resulting in reduced feed intake. Recent work demonstrates quite clearly that a soybean meal diet containing the same level of sulfur as that in canola diets results in comparable weight gain and feed intake in young broilers (Table 2.4). In this study, the unsupplemented canola diet contained 0.46% sulfur while the soy diet contained 0.14%. Adding sulfur to the soybean meal diet resulted in a decrease in weight gain. The level of sulfur in the unsupplemented canola diet (0.46%) lies part way between the levels found in the 0.26 and 0.39% sulfur supplemented soybean meal diet. Weight gain for the unsupplemented canola meal diet was 424 g while the average for the two soybean meal diets was 426 g. Higher dietary calcium levels partially overcame the growth depressing effect of high dietary sulfur thus demonstrating the negative effect of sulfur on calcium retention.

Table 2.4 Interaction of sulfur and calcium in canola and soybean meal diets

Protein source	*Suppl. S (%)*	*Total S (%)*	*Calcium level (%)*	*Weight gain (g)*
	-	.46	.37	424
Canola meal	.26	.72	.37	371
	-	.46	1.32	560
	.26	.72	1.32	481
	-	.14	.37	525
	.13	.27	.37	519
	.26	.40	.37	479
	.39	.53	.37	373
Soybean meal	-	.14	1.32	635
	.13	.27	1.32	598
	.26	.40	1.32	559
	.39	.53	1.32	451

In view of the reductions in appetite and calcium retention resulting from high dietary sulfur levels, these need to be closely monitored if substantial levels of canola meal are used. High levels of methionine or sulphate salts, along with ingredients with significant amounts of sulfur, such as phosphate supplements, can add considerable sulfur to a diet. Some sources of water can also be high in sulfur. Broilers can tolerate dietary sulfur levels of up to around 0.5% without any effect on performance while laying hens can handle even higher levels. There are reports which suggest that part of the response to increased levels of dietary sulfur is due to its influence in dietary acid-base balance. While Mongin, in his original work, suggested considering Na, K, and Cl in the dietary acid-base balance equation, S, being a strong anion, should also be considered in this equation if > 8% canola meal is used in poultry diets.

Potential Problems:

Canola meal contains less lysine than does soybean meal but slightly more sulfur amino acids per unit of dietary protein. It is also lower in energy than is soybean meal. Levels of up to 8% canola meal can be used in laying diets without any adverse effects on performance although egg size may be reduced by up to 1 g. Energy content is the factor that usually limits inclusion level. Levels of toxic goitrogens should be assayed periodically, together with tannins. Canola meal should not be fed to brown egg layers.

Nutrient Profile: (%)

Dry Matter	*90.0*	*Methionine*	*0.69*
Crude Protein	*37.5*	*Methionine + Cystine*	*1.3*
Metabolizable Energy:		*Lysine*	*2.21*
(kcal/kg)	*2000*	*Tryptophan*	*0.50*
(MJ/kg)	*8.37*	*Threonine*	*1.72*
Calcium	*0.65*	*Arginine*	*2.18*
Av. Phosphorus	*0.45*		
Sodium	*0.09*	*Dig Methionine*	*0.61*
Chloride	*0.05*	*Dig Meth + Cys*	*1.08*
Potassium	*1.45*	*Dig Lysine*	*1.76*
Selenium (ppm)	*0.90*	*Dig Tryptophan*	*0.38*
Fat	*1.5*	*Dig Threonine*	*1.30*
Linoleic acid	*0.5*	*Dig Arginine*	*1.92*
Crude Fiber	*12.0*		

Bulk Density:

kg/m³	***lb/ft³***	***lb/bushel***
625	*39*	*50*

Formulation Constraints:

Bird age	*Min.*	*Max.*	*Comments*
0-4 wk		*5%*	*Potential problems with tannins, low energy and high sulfur. Not for brown egg layers.*
4-8 wk		*8%*	
Adult		*8%*	

QA Schedule:

Moisture	*CP*	*Fat*	*Ca/P*	*AA's*	*Other*
All deliveries	*6 mos*	*12 mos*	*12 mos*	*12 mos*	*Tannins, sulfur and goitrogens each 6 mos.*

12. Corn gluten meal

Nutritional Characteristics:

Corn gluten meal contains around 60% CP and is a by-product of wet milling of corn, most of which is for manufacture of high-fructose corn syrup. Being high in protein, it is often compared to animal protein ingredients during formulation. The protein is merely a concentration of the original corn protein component brought about by removal of the starch in the endosperm. There are, in fact, two products often manufactured during wet milling, the alternate being corn gluten feed which contains only 20% CP, due to dilution with various hull material. In certain regions of the world, the two products are merely called 'corn gluten' and so this must be differentiated based on protein content. Corn gluten meal is very deficient in lysine, although with appropriate use of synthetic lysine sources, the product is very attractive where high nutrient density is required. Gluten meal is also very high in xanthophylls pigments (up to 300 mg/g) and is a very common ingredient where there is a need to pigment poultry products.

Potential Problems:

Periodically corn gluten feed (20% CP) is inadvertently formulated as corn gluten meal (60% CP). Using much more than 10% corn gluten meal will produce a visible increase in pigmentation of broilers and egg yolks.

Nutrient Profile: (%)

Dry Matter	*90.0*	*Methionine*	*1.61*
Crude Protein	*60.0*	*Methionine + Cystine*	*2.52*
Metabolizable Energy:		*Lysine*	*0.90*
(kcal/kg)	*3750*	*Tryptophan*	*0.30*
(MJ/kg)	*15.70*	*Threonine*	*1.70*
Calcium	*0.10*	*Arginine*	*2.20*
Av. Phosphorus	*0.21*		
Sodium	*0.10*	*Dig Methionine*	*1.44*
Chloride	*0.06*	*Dig Meth + Cys*	*2.22*
Potassium	*0.04*	*Dig Lysine*	*0.81*
Selenium (ppm)	*0.30*	*Dig Tryptophan*	*0.21*
Fat	*2.51*	*Dig Threonine*	*1.58*
Linoleic acid	*1.22*	*Dig Arginine*	*2.07*
Crude Fiber	*2.48*		

Bulk Density:

kg/m³	***lb/ft³***	***lb/bushel***
578	*36*	*46.1*

Formulation Constraints:

Bird age	***Min.***	***Max.***	***Comments***
0-4 wk		*15%*	*Pigmentations increases with > 10% inclusion.*
4-8 wk		*20%*	
8 wk+		*20%*	

QA Schedule:

Moisture	***CP***	***Fat***	***Ca/P***	***AA's***	***Other***
All deliveries	*3 mos*	*6 mos*	*6 mos*	*12 mos*	*-*

13. Cottonseed meal

Nutritional Characteristics:

Cottonseed meal is not usually considered in diets for poultry, although for obvious economic reasons it is often used in cottonseed producing areas. A high fiber content and potential contamination with gossypol are the major causes for concern. Gossypol is a yellow polyphenolic pigment found in the cottonseed 'gland'. In most meals, the total gossypol content will be around 1%, although of this, only about 0.1% will be free gossypol. The remaining bound gossypol is fairly inert, although binding can have occurred with lysine during processing, making both the gossypol and the lysine unavailable to the bird. So-called 'glandless' varieties of cottonseed are virtually free of gossypol.

Birds can tolerate fairly high levels of gossypol before there are general problems with performance although at much lower levels there can be discoloration of the yolk and albumen in eggs. Characteristically the gossypol causes a green-brown-black discoloration in the yolk depending upon gossypol levels, and the duration of egg storage. As egg storage time increases, the discoloration intensifies, especially at cool temperatures (5ºC) where there is more rapid change in yolk pH. Gossypol does complex with iron, and this activity can be used to effectively detoxify the meal. Adding iron at a 1:1 ratio in relation to free gossypol greatly increases the dietary inclusion rate possible in broiler diets and also the level at which free gossypol becomes a problem with laying hens. Because most cottonseed samples contain around 0.1% free gossypol, detoxification can be accomplished by adding 0.5 kg ferrous sulphate/tonne feed. With addition of iron, broilers can withstand up to 200 ppm free gossypol, and layers up to 30 ppm free gossypol without any adverse effects.

If cottonseed meal contains any residual oil, then cyclopropenoid fatty acids may contribute to egg discoloration. These fatty acids are deposited in the vitelline membrane, and alter its permeability to iron that is normally found only in the yolk. This leached iron complexes with conalbumin in the albumen producing a characteristic pink color. Addition of iron salts does not prevent this albumen discoloration, and the only preventative measure is to use cottonseed meals with very low residual fat content.

Potential Problems:

Yolk discoloration is the main concern, and so ideally, cottonseed meal should not be used for laying hens or breeders. The lysine in cottonseed is particularly prone to destruction due to overheating of meals during processing.

Nutrient Profile: (%)

Dry Matter	*90*	*Methionine*	*0.49*
Crude Protein	*41.0*	*Methionine + Cystine*	*1.11*
Metabolizable Energy:		*Lysine*	*1.67*
(kcal/kg)	*2350*	*Tryptophan*	*0.50*
(MJ/kg)	*9.83*	*Threonine*	*1.31*
Calcium	*0.15*	*Arginine*	*4.56*
Av. Phosphorus	*0.45*		
Sodium	*0.05*	*Dig Methionine*	*0.35*
Chloride	*0.03*	*Dig Meth + Cys*	*0.75*
Potassium	*1.10*	*Dig Lysine*	*1.18*
Selenium (ppm)	*0.06*	*Dig Tryptophan*	*0.35*
Fat	*0.50*	*Dig Threonine*	*0.90*
Linoleic acid	*0.21*	*Dig Arginine*	*3.68*
Crude Fiber	*14.50*		

Bulk Density:

kg/m³	***lb/ft³***	***lb/bushel***
644	*40.1*	*51.3*

Formulation Constraints:

Bird age	***Min.***	***Max.***	***Comments***
0-4 wk		*10%*	*Maximum levels dependent upon levels of free gossypol. Inadvisable for layers if alternative ingredients available.*
4-8 wk		*15%*	
8-18 wk		*20%*	
18 wk+		*10%*	

QA Schedule:

Moisture	***CP***	***Fat***	***Ca/P***	***AA's***	***Other***
All deliveries	*6 mos*	*6 mos*	*12 mos*	*12 mos*	*Gossypol 2-3 times each year*

14. Flaxseed

Other Names: Linseed

Nutritional Characteristics:

Flax is grown essentially for its oil content, although in Europe there is still some production of special varieties for linen production. Fat-extracted flax, which is commonly called linseed meal, has traditionally been used for ruminant feeds. Over the last few years, there has been interest in feeding full-fat flaxseed to poultry, because of its contribution of linolenic acid. Flax oil contains about 50% linolenic acid (18:3w3) which is the highest concentration of omega-3 fatty acids within vegetable oils. It has recently been shown that 18:3w3, and its desaturation products docosahexaenoic acid and eicosapentaenoic acid are important in human health, and especially for those individuals at risk from chronic heart disease. Government agencies in many countries now recognize the importance of linolenic acid in human health, suggesting the need to increase average daily intake, and especially intake in relation to that of linoleic acid.

Feeding flaxseeds to poultry results in direct incorporation of linolenic acid into poultry meat and also into eggs. Feeding laying hens 10% flax results in a 10-fold increase in egg yolk linolenic acid content and eating two such modified eggs each day provides adults with most of their daily recommended allowance of linolenic acid. For each 1% of flaxseed added to a layer diet, there will be a +40 mg increase in total omega-3 fatty acids per egg. Likewise, in broilers, each 1% flaxseed addition will increase total omega-3 fats in the carcass by +2% of total fat. Feeding layers 8% flaxseed will result in an egg with about 320 mg total omega-3 fatty acids. For broiler chickens, there is no need to feed flaxseed for the entire grow-out period. Feeding 10% flaxseed to broilers for only the last 14 d of grow-out, results in significant incorporation of omega-3 fatty acids in the meat. With cooked breast + skin there is an increase in omega-3 content from 150➛675 mg/100 g cooked product.

Linolenic acid enriched eggs and poultry meat are therefore an attractive alternative to consumption of oily fish. Linolenic acid is essentially responsible for the characteristic smell of ‘fish oils’ and undoubtedly flax oil does have a ‘paint-type’ smell. There is some concern about the taste and smell of linolenic acid-enriched poultry meat and this topic needs more careful study with controlled taste panel work. There is often discussion about the need to grind flaxseed. The seeds are very small, and for birds with an ‘immature’ gizzard it seems likely that some seeds will pass directly through the bird. Flaxseeds are quite difficult to grind, and are usually mixed 50:50 with ground corn before passing through a hammer mill. Perhaps the greatest benefit to grinding is seen with mash diets. Table 2.5 shows digestible amino acid values, determined with adult roosters for whole and ground flaxseed.

These digestibility values were determined using the force-feeding method, and so the bird is fed only the flaxseed, which is a novel situation to the bird. Over time gizzard activity may increase and so digestibility of whole seeds may improve. Using a classical AMEn bioassay, we have shown a consistent increase in AMEn of flaxseed when diets are steam crumbled (Table 2.6).

Table 2.5 Amino acid digestibility of flaxseed (%)

	Flaxseed	
	Whole	***Ground***
Methionine	*68*	*85*
Cystine	*68*	*87*
Lysine	*72*	*88*
Threonine	*65*	*82*
Tryptophan	*85*	*95*
Arginine	*71*	*92*
Isoleucine	*66*	*86*
Valine	*65*	*84*
Leucine	*67*	*87*

Courtesy Novus Int.

Table 2.6 Effect of steam crumbling on AMEn of flaxseed (kcal/kg)

Bird Type	***Mash***	***Steam Crumble***	□
Broiler chicken	*3560*	*4580*	*+31%*
Rooster	*3650*	*4280*	*+17%*
Laying hen	*3330*	*4140*	*+24%*

Adapted from Gonzalez (2000) and Bean (2002)

These assays were conducted at different times and with different samples of flaxseed. In another study there was an 18% improvement in AMEn for layers when flaxseed was extruded. Conventional pelleting seems sufficient to weaken the seed structure so as to allow greater digestibility of amino acids and energy.

With laying hens, there may be transitory problems with suddenly incorporating 8-10% flaxseed in the diet, usually manifested as reduced feed intake and/or wet sticky manure. These problems can usually be overcome by gradual introduction of flaxseed, using for example, 4% for one week, followed by 6% for another week and then the final 8-10% inclusion. It usually takes 15-20 d in order for omega-3 content of eggs to plateau at the desired level of 300 mg/egg. With prolonged feeding there is often greater incidence of liver hemorrhage in layers, even though mortality is rarely affected. Such hemorrhaging occurs even in the presence of 100-250 IU vitamin E/kg diet, which is a regular addition to flax-based diets. Disruption to liver function may become problematic if other stressors occur.

Potential Problems:

Flaxseed should be introduced gradually when feeding young layers. Weekly increments using 4-6 and 8-10% over 3 weeks are ideal to prevent feed refusal. Ground flaxseed is prone to oxidative rancidity, and so should be used within 2-3 weeks of processing. There seem to be advantages to steam pelleting diets contain-ing flaxseed. Flaxseed contains a number of antinutrients including mucilage, trypsin inhibitor, cyanogenic glycosides and considerable quantities of phytic acid. The mucilage is mainly pectin, found in the seed coat and can be 5-7% by weight. The mucilage undoubtedly contributes to more viscous excreta, and there is some evidence that ß-glucanase enzymes may be of some benefit, especially with young birds. Flaxseed may contain up to 50% of the level of trypsin inhibitors found in soybeans, and this is possibly the basis for response to heat treatment and steam pelleting of flaxseed. The main glucosides yield hydrocyanic acid upon hydrolysis, and this has an adverse effect on many enzyme systems involved in energy metabolism.

Nutrient Profile: (%)

Dry Matter	*90.0*	*Methionine*	*0.41*
Crude Protein	*22.0*	*Methionine + Cystine*	*0.82*
Metabolizable Energy:		*Lysine*	*0.89*
(kcal/kg)	*3500[1]-4200[2]*	*Tryptophan*	*0.29*
(MJ/kg)	*14.64–17.60*	*Threonine*	*0.82*
Calcium	*0.25*	*Arginine*	*2.10*
Av. Phosphorus	*0.17*		
Sodium	*0.08*	*Dig Methionine*	*0.28[1]-0.35[2]*
Chloride	*0.05*	*Dig Meth + Cys*	*0.56-0.70*
Potassium	*1.20*	*Dig Lysine*	*0.64-0.78*
Selenium (ppm)	*0.11*	*Dig Tryptophan*	*0.25-0.27*
Fat	*34.0*	*Dig Threonine*	*0.53-0.67*
Linoleic acid	*5.2*	*Dig Arginine*	*1.49-1.93*
Crude Fiber	*6.0*		

[1] Mash; [2] Pellets

Bulk Density:

kg/m³	*lb/ft³*	*lb/bushel*
700	*43.5*	*55.7*

Formulation Constraints:

Bird age	*Min.*	*Max.*	*Comments*
0-4 wk		*8*	*Gradual introduction suggested to prevent feed refusal.*
4-8 wk		*8*	
> 8 wk		*10*	

QA Schedule:

Moisture	*CP*	*Fat*	*Ca/P*	*AA's*	*Other*
All deliveries	*6 mos*	*6 mos*	*12 mos*	*12 mos*	*Fatty acid profile each 12 mos.*

15. Meat meal

Other names: Meat and bone meal

Nutritional Characteristics:

Meat meal is a by-product of beef or swine processing, and this can be of variable composition. For each 1 tonne of meat prepared for human consumption, about 300 kg is discarded as inedible product, and of this, about 200 kg is rendered into meat meal. In the past, meat meal referred only to soft tissue products, while meat and bone meal also contained variable quantities of bone. Today, meat meal most commonly refers to animal by-products with bone where protein level is around 50% and calcium and phosphorus are at 8% and 4% respectively. Because the mineral comes essentially from bone, the calcium phosphorus ratio should be around 2:1 and deviations from this usually indicate adulteration with other mineral sources.

Variation in calcium and phosphorus content is still problematic, and the potential for overfeeding phosphorus is a major reason for upper limits of inclusion level. Meat meals usually contain about 12% fat and the best quality meals will be stabilized with antioxidants such as ethoxyquin. Some of the variability in composition is now being resolved by so-called 'blenders' that source various meat meal products and mix these to produce more consistent meat meals.

Meat meals are currently not used in Europe because of the problems they have had with BSE (Bovine Spongiform Encephalopathy). It seems as though conventional rendering treatments do not inactivate the causative prions. However, pressure treatment to 30 psi (200 kPa) for about 30 minutes during or after rendering seems to destroy prions. Parsons and co-workers at the University of Illinois have shown that such pressure treatment can reduce lysine digestibility from 75% to 55% and cystine from 65% down to 30%. If extreme pressure treatment becomes standard during rendering of meat meal, it will obviously be necessary to carefully re-evaluate nutrient availability.

Recent evidence suggests that the metabolizable energy content of meat meal, and other animal protein by-products, is higher than the most common estimates used in the past. In bioassays, ME values determined at inclusion levels of 5 –10% are much higher than those determined at more classical levels of 40 – 50% inclusion. The reason for the higher values is unclear, although it may relate to synergism between protein or fat sources, and these are maximized at low inclusion levels. Alternatively, with very high inclusion levels of meat meal, the high calcium levels involved may cause problems with fat utilization due to soap formation, and so energy retention will be reduced. Another reason for change in energy value, is that commercial samples of meat meal today contain less bone than occurred some 20 – 30 years ago. Dale suggests that the TMEn of meat meal from beef is around 2,450 kcal/kg while that from pork is closer to 2,850 kcal/kg.

Another concern with meat meal is microbial content, and especially the potential for contamination with salmonella. Due to increasing awareness and concern about microbial quality, surveys show that the incidence of contamination has declined, but remains at around 10%. Protein blends are at highest risk, because obviously a single contaminated source can lead to spread of salmonella in various blended products. One means of reducing microbial load is to treat freshly processed meals with organic acids. In many studies, it is shown that meals are virtually sterile when

they emerge from the cooking chambers, and that problems most often occur with recontamination. Certainly most feed ingredients contain salmonella, however, because of the relative proportion of meat meals used in a diet, the actual chance of contamination for a single bird may, in fact, come from corn (Table 2.7).

The relative risk to an individual bird is, therefore, claimed to be higher from cereals because, even though they are not usually contaminated, their much higher inclusion level results in a greater potential risk. However, this type of argument is open to the real criticism that meat meals are much more likely to contaminate the feed, trucks, equipment etc., and that salmonella numbers will likely increase after feed manufacture. Pelleted and extruded/expanded diets will have much lower microbial counts than corresponding mash diets.

Unfortunately, there is variability in nutrient availability of conventionally rendered meat meal, where lysine digestibility, for example, can vary from 70 to 88%. Such variability is not highly correlated with simple *in vitro* assays such as pepsin digestibility and KOH solubility.

Potential problems:

Meat meal should contain no more than 4% phosphorus and 8% calcium, since higher ash content will reduce its energy value. Nutrient availability is variable across suppliers, and so it is important to have adequate quality control procedures in place, and especially when there is a change in supplier.

Table 2.7 Relative risk due to salmonella from various ingredients

	Salmonella Contamination (%)	*Diet (%)*	*Relative Risk Factor*
Corn	*1*	*60*	*60*
Vegetable proteins	*8*	*30*	*24*
Meat meals	*10*	*5*	*50*

Nutrient Profile: (%)

Dry Matter	90.0	Methionine	0.71
Crude Protein	50.0	Methionine + Cystine	1.32
Metabolizable Energy:		Lysine	2.68
(kcal/kg)	2450 - 2850	Tryptophan	0.36
(MJ/kg)	10.25 - 11.92	Threonine	1.52
Calcium	8.0	Arginine	3.50
Av. Phosphorus	4.0		
Sodium	0.50	Dig Methionine	0.62
Chloride	0.90	Dig Meth + Cys	0.95
Potassium	1.25	Dig Lysine	2.09
Selenium (ppm)	0.4	Dig Tryptophan	0.26
Fat	11.5	Dig Threonine	1.17
Linoleic acid	1.82	Dig Arginine	2.78
Crude Fiber	-		

Bulk Density:

kg/m^3	lb/ft^3	lb/bushel
394	37	47.4

Formulation Constraints:

Bird age	Min.	Max.	Comments
0-4 wk		6%	Main concern is level of Ca and P, and ash
4-8 wk		8%	
> 8 wk		8%	

QA Schedule:

Moisture	CP	Fat	Ca/P	AA's	Other
All deliveries →				Yearly	Fatty acid profile yearly. Salmonella each 3 months.

16. Poultry by-product meal

Other Names: Poultry Meal, PBM Nutritional Characteristics:

As for meat meal, poultry by-product meal is produced essentially from waste generated during poultry meat processing. Because only one species is used, PBM should be a more consistent product than is meat meal, and certainly calcium and phosphorus levels will be lower. Variability in composition relates to whether or not feathers are added during processing or kept separate to produce feather meal. PBM and feathers are best treated using different conditions, because feathers require more extreme heat in order to hydrolyze the keratin proteins. PBM with feathers may therefore mean that either the feather proteins are under-cooked or that the offal proteins are overcooked. Overcooking usually results in a much darker colored product. PBM contains more unsaturated fats than does meat meal, and so if much more than 0.5% fat remains in the finished product, it should be stabilized with an antioxidant.

Because of problems of disposal of spent layers, there is now some production of 'spent hen meal' which is essentially produced by rendering the whole body, including feathers. Such spent hen meal contains around 11% fat and 20% ash, with 70% crude protein. Methionine, TSAA and lysine in such samples are around 1.2%, 2.5% and 3.5% respectively, with digestibility of methionine and lysine at 85%, while cystine is closer to 60% digestible. As with poultry by-product meal, the ME of spent hen meal is influenced by content of ash, fat and protein, with a mean value around 2,800 kcal/kg.

There is also current interest in ensiling various poultry carcasses and/or poultry by-products prior to heat processing. Ensiling allows for more control over microbial contamination prior to processing, and allows the potential to better utilize smaller quantities of poultry carcasses on-farm or from sites more distant to the PBM processing plant. Ensiling is also being considered as a means of handling spent layers prior to production of PBM. Poultry carcasses or offal do not contain sufficient fermentable carbohydrate to allow lactic acid fermentation which will quickly reduce pH to about 4.2 and stabilize the product. These lactic acid producing microbes can therefore be encouraged to proliferate by adding, for example, 10% molasses or 10% dried whey to ground carcasses. These mixtures quickly stabilize at around pH 4.2 – 4.5, and can be held for 10 – 15d prior to manufacture of PBM. Carcasses from older birds may require slightly higher levels of theses carbohydrates, and because of their inherently high fat content, may be mixed with products such as soybean meal in order to improve handling characteristics. Ensiled whole carcasses, as is now being produced with spent fowl, may present problems with availability of feather proteins for reasons outlined previously in terms of ideal processing conditions for tissue versus feathers. In the future, this problem may be resolved by adding feather-degrading enzymes to the ensiling mixture.

Potential problems:

Nutritive value will be positively correlated with protein and fat content and negatively correlated with ash. Cystine content will give an indication if feathers were included during processing, which will detract from amino acid digestibility.

Nutrient Profile: (%)

Dry Matter	90.0	Methionine	1.3
Crude Protein	60.0	Methionine + Cystine	3.3
Metabolizable Energy:		Lysine	3.4
(kcal/kg)	2950	Tryptophan	0.4
(MJ/kg)	12.34	Threonine	2.2
Calcium	3.60	Arginine	3.5
Av. Phosphorus	2.10		
Sodium	0.36	Dig Methionine	1.1
Chloride	0.40	Dig Meth + Cys	2.3
Potassium	0.28	Dig Lysine	2.7
Selenium (ppm)	0.90	Dig Tryptophan	0.3
Fat	8.50	Dig Threonine	1.8
Linoleic acid	2.50	Dig Arginine	3.0
Crude Fiber	1.9		

Bulk Density:

kg/m^3	lb/ft^3	lb/bushel
578	36.0	46.1

FormulationConstraints:

Bird age	Min.	Max.	Comments
0-4 wk		8%	No major concerns other than fat stability
4-8 wk		10%	
> 8 wk		10%	

QA Schedule:

Moisture	CP	Fat	Ca/P	AA's	Other
All samples	Weekly	Weekly	Weekly	Yearly	Digestible amino acids, including cystine, yearly

17. Feather meal

Nutritional Characteristics:

Feather meal can be an excellent source of crude protein where this is needed to meet regulatory requirements. However, its use is severely limited by deficiencies of several amino acids, including methionine, lysine and histidine. Feather meal usually contains about 4.5 – 5.0% cystine, and this should be around 60% digestible. The energy value of feather meal is quite high, being around 3300 kcal ME/kg, and Dale and co-workers at the University of Georgia suggests TMEn of feather meal is highly correlated with its fat content (2860 + 77 x % fat, kcal/kg). Variability in quality is undoubtedly related to control over processing conditions. Feathers are partially dried and then steam-treated to induce hydrolysis, and within reason, the higher the temperature and/or longer the processing time, the better the chance of complete hydrolysis. Obviously extreme processing conditions will cause destruction of heat-labile amino acids such as lysine. As a generalization, the lower the processing and drying temperatures, the lower the level of cystine digestibility. Research has shown processing conditions to result in digestible cystine levels as low as 45% with low cooking temperature, to as high as 65% with higher temperatures for longer durations. Because feather meal is an important contributor to TSAA in the diet, the level of digestible cystine is a critical factor in evaluating nutritive value.

High pressure, unless for a short duration, seems to reduce amino acid digestibility, and again this is especially critical for cystine. Under extreme processing conditions it seems as though sulfur can be volatilized, likely as hydrogen sulfide, and so another simple test for protein quality, is total sulfur content. Sulfur level should be just over 2%, and any decline is likely a reflection of higher than normal processing temperature, time and/or pressure, all of which will adversely affect amino acid digestibility.

Feather meal also contains an amino acid called lanthionine, which is not normally found in animal tissue. Total lanthionine levels can therefore be used in assaying meat meal products for potential contamination with feathers. Lanthionine can occur as a breakdown product of cystine, and there are some research results which indicate a very good correlation between high lanthionine levels and poor digestibility of most other amino acids. In most feather meal samples, lanthionine levels should be at 20 – 30% of total cystine levels. A potential problem in using lanthionine assays in quality control programs, is that it is readily oxidized by performic acid, which is a common step used in preparation of samples for amino acid analysis and particularly where cystine levels are of interest.

As with other animal proteins, there is current interest in alternate methods of processing. Treating feathers with enzyme mixtures that presumably contain keratinase enzyme together with NaOH has been shown to improve overall protein digestibility and bird performance. More recently, it has been shown that a pre-fermentation with bacteria such as *Bacillus licheniformis* for 5 d at 50ºC, produces a feather lysate that is comparable in feeding value to soybean meal when amino acid balance is accounted for.

Potential problems:

Amino acid digestibility, and especially cystine digestibility is greatly influenced by processing conditions. Monitoring total sulfur levels may be a simple method of assessing consistency of processing conditions.

Nutrient Profile: (%)

Dry Matter	*90.0*	*Methionine*	*0.60*
Crude Protein	*85.0*	*Methionine + Cystine*	*6.10*
Metabolizable Energy:		*Lysine*	*1.72*
(kcal/kg)	*3000*	*Tryptophan*	*0.60*
(MJ/kg)	*12.55*	*Threonine*	*4.51*
Calcium	*0.20*	*Arginine*	*6.42*
Av. Phosphorus	*0.70*		
Sodium	*0.70*	*Dig Methionine*	*0.47*
Chloride	*0.40*	*Dig Meth + Cys*	*2.85*
Potassium	*0.30*	*Dig Lysine*	*1.10*
Selenium (ppm)	*0.72*	*Dig Tryptophan*	*0.41*
Fat	*2.50*	*Dig Threonine*	*3.15*
Linoleic acid	*0.10*	*Dig Arginine*	*5.05*
Crude Fiber	*1.50*		

Bulk Density:

kg/m^3	***lb/ft^3***	***lb/bushel***
460	*28.7*	*36.7*

Formulation Constraints:

Bird age	***Min.***	***Max.***	***Comments***
0-4 wk		*2%*	*Amino acid digestibility the main concern*
4-8 wk		*3%*	
> 8 wk		*3%*	

QA Schedule:

Moisture	***CP***	***Fat***	***Ca/P***	***AA's***	***Other***
All deliveries	*Weekly*	*Monthly*	*6 mos*	*6 mos*	*Total sulfur each 3 months*

18. Fish meal

Other names: Herring meal; White Fish meal; Menhaden meal

Nutritional Characteristics:

Because of the decline in activities of most fisheries directed at human consumption, fish meals are now almost exclusively produced from smaller oily fish caught specifically for meal manufacture. Menhaden and anchovy are the main fish species used for meal manufacture, with lesser quantities of herring meal produced in Europe. Fish meal is usually an excellent source of essential amino acids, while energy level is largely dependent upon residual oil content. Because of variable oil and protein content, expected ME value can be calculated based on knowledge of their composition in the meal.

ME (kcal/kg) = 3000 ± (Deviation in % fat x 8600) ± (Deviation in % CP x 3900)
Where standard fat content is 2%, and CP is 60%.

Therefore, a 4% fat, 63% CP sample is expected to have an ME of 3289 kcal/kg, while a 1% fat, 58% CP sample will have ME closer to 2836 kcal/kg. The ash content of fishmeal will be predominantly calcium and phosphorus and the latter can be around 90% available, as is phosphorus from any quality animal protein.

All fish meals should be stabilized with antioxidants. This is especially true for high oil content samples, but even with only 2% residual oil, there is good evidence to show reduced oxidation (in terms of production of oxidation products and free fatty acids, as well as reduced heat production) by adding 100 ppm ethoxyquin during manufacture.

Potential problems in feeding fish meal are taint of both eggs and meat, and gizzard erosion in young birds. With inadequately heat-treated fishmeal, especially from fresh water fish, there is also the potential problem of excessive thiaminase activity. Depending upon geographical location, taint in eggs and meat can be detected by consumers when birds are fed much more than 4 – 5% fish meal. Problems of taint will be more acute with high fat samples, and of course, the problems are most acute if fish oil *per se* is used. Even at levels as low as 2.5% fish meal, some brown egg birds produce tainted eggs which may be related to the trimethylamine content of fish meal, and the genetic predisposition of certain birds failing to produce sufficient trimethylamine oxidase. Excess trimethylamine is shunted to the egg, producing a characteristic fishy taint (see also canola meal). The trimethylamine content of fish meal is around 50 – 60 mg/kg, and assuming a 2.5% inclusion level, and feed intake of such brown egg layers of 115 g/day, means that the bird is taking in about 0.2 mg/day. Each affected egg contains around 0.8 mg, and so, it is obvious that the diet contains sources of trimethylamine other than fish meal, or that there is microbial synthesis in the intestine.

For young chicks, and especially the broiler chicken, a major concern with feeding fish meal, is gizzard erosion. A proportion of chicks fed almost any level of fish meal develop gizzard lesions, although there is a strong dose-response. Affected birds have signs ranging from small localized cracks in the gizzard lining, through to severe erosion and hemorrhage which ultimately leads to total destruction of the lining. The thick lining is required for preventing degrading effects of acid and pepsin produced by the proventriculus. Because of disrupted protein

degradation, the affected birds show very slow growth rate. The condition is most common when fish meal is included in the diet, although similar signs are seen with birds fed a high level of copper (250 ppm) or vitamin K deficient diets, or simply induced by starvation. Gizzard erosion was initially thought to be associated with histamine levels in fish meal. Feeding histamine to birds simulates the condition, as does feeding a heated semi-purified diet containing histidine. Fish meals contain histamine, and following microbial degradation during pre-cooking storage, bacteria possessing histidine decarboxylase will convert variable quantities from histidine to histamine. Histamine has the effect of stimulating excessive acid production by the proventriculus, and it is this acid environment that initiates breakdown of the gizzard lining. A product known as gizzerosine has been isolated from fish meal, and this has histamine-type properties in terms of stimulating acid secretion. Gizzerosine is formed by heating histidine and a protein during manufacture of fish meal. The most common components are lysine and histidine. Gizzerosine is almost 10x as potent as is histamine in stimulating proventricular acid production and some 300x more potent in causing gizzard erosion. Currently the only useful screening test is to feed high levels (25 – 50%) to young chicks and score the degree of gizzard lesions (see ingredient quality control Section 2.2 i).

Because the mode of action of gizzerosine is via acid production and a change in gizzard pH, there have been attempts at adding buffers to prevent the problem. For example adding sodium bicarbonate has been reported to lessen the severity of gizzard erosion. However, levels as high as 10 kg/tonne are required to change gizzard pH by only 0.3 units. Variable levels of gizzerosine in fish meals likely relate to pre-processing holding time and storage temperature, and also to the time and temperature of the cooking and oil extraction procedures.

Potential Problems:

Taint of meat or eggs can occur with much more than 2% fish meal in the diet. Fish meal should be stabilized with an antioxidant, and this factor is critical when residual fat content exceeds 2%. With young chicks, gizzard erosion is a consequence of using poorly processed, or inadequately stored fish meal.

Nutrient Profile: (%)

Dry Matter	*90.0*	*Methionine*	*1.82*
Crude Protein	*60.0*	*Methionine + Cystine*	*2.92*
Metabolizable Energy:		*Lysine*	*5.28*
(kcal/kg)	*2750*	*Tryptophan*	*0.58*
(MJ/kg)	*11.51*	*Threonine*	*3.01*
Calcium	*6.50*	*Arginine*	*4.05*
Av. Phosphorus	*3.50*		
Sodium	*0.47*	*Dig Methionine*	*1.62*
Chloride	*0.55*	*Dig Meth + Cys*	*2.42*
Potassium	*0.32*	*Dig Lysine*	*4.72*
Selenium (ppm)	*1.85*	*Dig Tryptophan*	*0.48*
Fat	*2.0*	*Dig Threonine*	*2.50*
Linoleic acid	*0.3*	*Dig Arginine*	*3.62*
Crude Fiber	*1.0*		

Bulk Density:

kg/m^3	lb/ft^3	lb/bushel
674	*42*	*53.8*

Formulation Constraints:

Bird age	Min.	Max.	Comments
0-4 wk		*8%*	*Taint problems likely in most markets at levels much in excess of 2%*
4-8 wk		*10%*	
> 8 wk		*10%*	

QA Schedule:

Moisture	CP	Fat	Ca/P	AA's	Other
All deliveries	→	*Monthly*	→	*12 mos*	*Fat oxidation, gizzerosine each 6 mos.*

19. Fats and oils

Nutritional Characteristics:

Fats provide a concentrated source of energy, and so relatively small changes in inclusion levels can have significant effects on diet ME. Most fats are handled as liquids, and this means heating of most fats and fat blends that contain appreciable quantities of saturated fatty acids.

Depending upon the demands for pellet durability, 3 – 4% is the maximum level of fat that can be mixed with the other diet ingredients. To this, up to 2 – 3% can be added as a spray-on coat to the formed pellet. Alternate technology of spraying fat onto the hot pellet as it emerges from the pellet die means that much higher inclusions are possible since the hot pellet seems better able to adsorb the fat. Under these conditions, there is concern for manufacturers who demand extreme pellet durability, since fines will already be treated with extra fat, prior to their recycling through the pellet mill.

All fats and oils must be treated with an antioxidant which ideally should be added at the point of manufacture. Fats held in heated tanks at the mill must be protected from rancidity. The more unsaturated a fat, the greater the chance of rancidity. Fats also provide varying quantities of the essential nutrient linoleic acid. Unless a diet contains considerable quantities of corn, it may be deficient in linoleic acid, because all diets should contain a minimum of 1%. A major problem facing the industry at the moment is the increasing use of restaurant grease in feed-grade fats. These greases are obviously of variable composition in terms of fatty acid profile and content of free fatty acids. Also, dependent upon the degree of heating that they have been subjected to, these greases can contain significant quantities of undesirable break-down products.

In order to ensure adequate levels of linoleic acid, and to improve palatability and reduce dustiness of diets, all diets require a minimum of 1% added fat, regardless of other economic or nutritional considerations. There is considerable information published on factors that influence fat digestibility, but in most instances, this knowledge is not used during formulation. In large part variability is due to the fact that digestibility is not a static entity for any fat, but rather its utilization is variable with such factors as bird age, fat composition and inclusion level. Unfortunately, these variables are difficult to factor into formulation programs. Other concerns about fats are their potential for rancidity and effect on carcass composition. Following are descriptions of the major types of fat used in the feed industry. Table 2.8 summarizes the fatty acid profile and ME of the most common fat sources used in poultry nutrition. An attempt has been made to predict fat ME based on bird age.

19a. Tallow

Tallow has traditionally been the principle fat source used in poultry nutrition. However, over the last 10 years, there has been less use of pure tallow and greater use of blended fats and oils. Tallow is solid at room temperature and this presents some problems at the mill, especially when heated

Table 2.8 Nutrient composition of fats and oils

		Metabolizable energy (kcal/kg)		*Fat*	*M.I.U.*[5]	*Fatty acid profile (%)*							
	Ingredient	***1***[1]	***2***[2]	*%*	*%*	***12:0***	***14:0***	***16:0***	***18:0***	***16:1***	***18:1***	***18:2***	***18:3***
19a	*Tallow*	*7400*	*8000*	*98*	*2*		*4.0*	*25.0*	*24.0*	*0.5*	*43.0*	*2.0*	*0.5*
19b	*Poultry fat*	*8200*	*9000*	*98*	*2*		*1.0*	*20.0*	*4.0*	*5.5*	*41.0*	*25.0*	*1.5*
19c	*Fish oil*	*8600*	*9000*	*99*	*1*		*8.0*	*21.0*	*4.0*	*15.0*	*17.2*	*4.4*	*3.0*[3]
19d	*Vegetable oil*	*8800*	*9200*	*99*	*1*		*0.5*	*13.0*	*1.0*	*0.5*	*31.0*	*50.0*	*2.0*
19e	*Coconut oil*	*7000*	*8000*	*99*	*1*	*50.0*[4]	*20.0*	*6.0*	*2.5*	*0.5*	*4.0*	*2.1*	*0.2*
19f	*Palm oil*	*7200*	*8000*	*99*	*1*		*2.0*	*42.4*	*3.5*	*0.7*	*42.1*	*8.0*	*0.4*
19g	*Vegetable soapstock*	*7800*	*8100*	*98*	*2*		*0.3*	*18.0*	*3.0*	*0.3*	*29.0*	*46.0*	*0.8*
19h	*Animal-Vegetable blend*	*8200*	*8600*	*98*	*2*		*2.1*	*21.0*	*15.0*	*0.4*	*32.0*	*26.0*	*0.6*
19i	*Restaurant grease*	*8100*	*8900*	*98*	*2*		*1.0*	*18.0*	*13.0*	*2.5*	*42.0*	*16.0*	*1.0*

[1]ME for young birds up to 3 weeks of age; [2]ME for birds after 3 weeks of age; [3]Contains 25% unsaturated fatty acids □ 20:4; [4]Contains 15% saturated fatty acids □10:0; [5]Moisture, impurities, unsaponifiables.

fats are added to very cold ingredients originating from unheated outside silos. Being highly saturated, tallow is not well digested by young chickens, although there is some evidence of better utilization by young turkeys. The digestibility of tallow can be greatly improved by the addition of bile salts suggesting this to be a limiting feature of young chicks. However, the use of such salts is not economical and so inclusion of pure tallow must be severely restricted in diets for birds less than 15 – 17 d of age.

19b. Poultry Fat

This fat source is ideal for most types and ages of poultry in terms of its fatty acid profile. Due to its digestibility, consistent quality and residual flavor, it is in high demand by the pet food industry, and this unfortunately reduces its supply to the poultry industry. As occurs with poultry meal, there is a concern with integrated poultry operations that fat-soluble contaminants may be continually cycled (and concentrated) through the birds. This can obviously be resolved by breaking the cycle for a 1 or 2 bird cycle.

19c. Fish Oil

There is current interest in the use of fish oils in diets for humans and animals, since its distinctive component of long chain fatty acids is thought beneficial for human health. Feeding moderate levels of fish oils to broiler chickens has been shown to increase the eicosapentaenoic acid content of meat. However, with dietary levels in excess of 1%, distinct fish type odour is often present in both meat and eggs, which is due mainly to the contribution of the omega-3 fatty acids.

19d. Vegetable Oil

A large range of vegetable oils is available as an energy source, although under most situations, competition with the human food industry makes them uneconomic for animal feeds. Most vegetable oils provide around 8700 kcal ME/kg and are ideal ingredients for very young birds. If these oils are attractively priced as feed ingredients, then the reason(s) for refusal by the human food industry should be ascertained e.g. contaminants.

19e. Coconut Oil

Coconut oil is a rather unusual ingredient in that it is a very saturated oil. Coconut oil is more saturated than is tallow. It contains 50% of saturated fatty acids with chain length less than 12:0. In many respects, it is at the opposite end of the spectrum to fish oil in terms of fatty acid profile. There has been relatively little work conducted on the nutritional value of coconut oil, although due to its saturated fatty acid content it will be less well digested, especially by young birds. However recent evidence suggests very high digestibility by young birds of medium chain triglycerides, such as C:8 and C:10 as found in coconut oil. These medium length fatty acids do not need bile for emulsification or prior incorporation within a micelle prior to absorption.

19f. Palm Oil

Palm oil production is now only second to soybean oil in world production. Palm oil is produced from the pulpy flesh of the fruit, while smaller quantities of palm kernel oil are extracted from the small nuts held within the body of the fruit. Palm oil is highly saturated, and so will have limited usefulness for very young birds. Also, soapstocks produced from palm oil, because of their free fatty acid content, will be best suited for older birds. There is potential for using palm and coconut oils as blends with more unsaturated oils and soapstocks, so as to benefit from potential fatty acid synergism.

19g. Soapstock (Acidulated soapstock)

As a by-product of the vegetable oil refining industry, soapstocks provide a good source of energy and essential fatty acids. Soapstocks can be quite high in free fatty acids, and so stabilization with an antioxidant is essential. Soapstocks may also be acidulated, and this may pose problems with corrosion of metallic equipment. Some impurities may be added to soapstocks as a means of pollution-free disposal by refineries, and therefore quality control becomes more critical with these products. Moisture level may also be high in some samples, and this simple test is worthwhile for economic evaluation.

19h. Animal-Vegetable Blend Fat

Some manufacturers mix animal and vegetable based fats, to give so-called blended products. The vegetable source is usually soapstock material. The blend has the advantage of allowing for some synergism between saturated fatty acids of animal origin and unsaturates from the soapstock. Animal-vegetable blends are therefore ideally suited for most classes of poultry without the adverse problem of unduly increasing the unsaturates in meat which can lead to increased rate of oxidative rancidity (reduced shelf life).

19i. Restaurant Grease

An increasing proportion of feed fats is now derived from cooking fats and oils, and the generic product is termed restaurant grease. Its use has increased mainly due to problems of alternate disposal. Traditionally restaurant greases were predominately tallow or lard based products and this posed some problems in collection and transportation of the solid material. In recent years, due to consumer concerns about saturated fats, most major fast food and restaurant chains have changed to hydrogenated vegetable cooking fats and oils. The fats are hydrogenated to give them protection against high-temperature cooking. Today, restaurant greases contain higher levels of oleic acid, and much of this will be trans-oleate. Assuming there has not been excessive heating, and that the grease has been cleaned and contains a minimum of impurities, then the energy value will be comparable to that of poultry fat. Future use of non-fat 'cooking fats' will lead to considerable variation in the nutrient profile of these products.

19j. Conjugated Linoleic Acid (CLA)

CLA is an isomer of conventional linoleic acid, but unlike linoleic, there are numerous health benefits claimed for CLA. It is claimed to help control glucose metabolism in diabetic mammals, and more importantly to prevent and/or control the growth of certain cancerous tumors. CLA is normally found in dairy products, representing around 0.3% of total fat. Turkey meat is also high in CLA. Feeding CLA to layers results in bioaccumulation in the egg, much as for any fatty acid, and so there is potential for producing CLA enriched designer eggs. It seems as though the AMEn of CLA is comparable to that of linoleic acid, suggesting that the two fatty acids are comparably metabolized.

It is possible that CLA is not elongated as in linoleic acid during metabolism and so this has posed questions about adequacy of prostaglandin synthesis, and hence immune function. There are some reports of altered lipid metabolism in embryos and young chicks from eggs hatched from hens fed 1 g CLA daily. There is some discussion about whether or not synthetic sources of CLA actually mimic the beneficial anti-cancerous properties of 'natural' CLA found in dairy products.

Important Considerations:

Fats and oils are probably the most problematic of all the ingredients used in poultry feeds. They require special handling and storage facilities and are prone to oxidation over time. Their fatty acid profile, the level of free fatty acids and degree of hydrogenation can all influence digestibility. Unlike most other ingredients, fat digestion can be age dependent, since young birds have reduced ability to digest saturated and hydrogenated fats.

a. Moisture, Impurities, Unsaponifiables

Feed grade fats will always contain some non-fat material that is generally classified as M.I.U. (moisture, impurities and unsaponifiables). Because these impurities provide no energy or little energy, they act as diluents. A recent survey indicated M.I.U's to range from 1 – 9%. Each 1% MIU means a loss in effective value of the fat by about \$3 - \$4/tonne, and more importantly, energy contribution will be less than expected. The major contaminants are moisture and minerals. It seems as though moisture can be quickly detected by Near Infra Red Analysis. Moisture and minerals also lead to increased peroxidation.

b. Rancidity and Oxidation

The feeding value of fats can obviously be affected by oxidative rancidity that occurs prior to, or after feed preparation. Rancidity can influence the organoleptic qualities of fat, as well as color and 'texture' and can cause destruction of other fat soluble nutrients, such as vitamins, both in the diet and the bird's body stores. Oxidation is essentially a degradation process that occurs at the double-bond in the glyceride structure. Because presence of double-bonds infers unsaturation, then naturally the more unsaturated a fat, the greater the chance of rancidity. The initial step is the formation of a fatty free radical when hydrogen leaves the α-methyl carbon in the unsaturated group of the fat. The resultant free radical then becomes very susceptible to attack by atmospheric oxygen (or mineral oxides) to form unstable peroxide free radicals. These peroxide free radicals are themselves potent catalysts, and so the process becomes autocatalytic and rancidity can develop quickly. Breakdown products include ketones, aldehydes and short chain fatty acids which give the fat its characteristic 'rancid' odour. Animal fats develop a slight rancid odour when peroxide levels reach 20 meq/kg while for vegetable oils problems start at around 80 meq/kg.

Oxidative rancidity leads to a loss in energy value, together with the potential degradation of the bird's lipid stores and reserves of fat-soluble vitamins. Fortunately we have some control over these processes through the judicious use of antioxidants. Most antioxidants essentially function as free radical acceptors – these radical-antioxidant complexes are, however, stable and do not cause autocatalytic reactions. Their effectiveness, therefore, relies on adequate dispersion in the fat immediately after processing. As an additional safety factor, most diets will also contain an antioxidant added via the premix. The Active Oxygen Method (AOM) is most commonly used to indicate potential for rancidity. After 20 h treatment with oxygen, quality fats should develop no more than 20 meq peroxides/kg.

Time is a very important factor in the AOM test, because peroxides can break down and disappear with extended treatment. For this reason, some labs will provide peroxide values at 0, 10 and 20 hr. A newer analytical technique is the Oil Stability Index (OSI). This is similar to AOM, but instead of measuring initial peroxide products, measures the accumulation of secondary breakdown compounds. The assay is highly automated and records the time necessary to produce a given quantity of breakdown products such as short chain volatile fatty acids.

c. Fatty Acid Profile

Fat composition will influence overall fat utilization because different components are digested with varying efficiency. It is generally recognized that following digestion, micelle formation is an important prerequisite to absorption. Micelles are complexes of bile salts, fatty acids, some monoglycerides and perhaps glycerol. The conjugation of bile salts with fatty acids is an essential prerequisite for transportation to and absorption through the microvilli of the small intestine. Polar unsaturated fatty acids and monoglycerides readily form this important association. However, micelles themselves have the ability to solubilize non-polar compounds such as saturated fatty acids. Fat absorption is, therefore, dependent upon there being an adequate supply of bile salts and an appropriate balance of unsaturates:saturates.

Taking into account the balance of saturated to unsaturated fatty acids can be used to advantage in designing fat blends. This type of synergistic effect is best demonstrated using pure fatty acids (Table 2.9). In this study, the metabolizable energy of the 50:50 mixture of the unsaturated oleic acid with the saturated palmitic acid, is 5% higher than the expected value based on the mean value of 2710 kcal/kg. We therefore have a boost of 5% in available energy that likely comes from greater utilization of the palmitic acid because of the presence of the unsaturated oleic acid.

Table 2.9 Metabolizable energy of layer diets containing various fatty acids

	Determined	*Expected*
	ME (kcal/kg)	
Oleic	*2920*	
Palmitic	*2500*	
50:50 mixture	*2850 (+5%)*	*2710*

(Atteh and Leeson, 1985)

This type of synergism can, however, have a confounding effect on some research results. If we want to measure the digestibility of corn, it is possible to feed just corn for a short period of time and conduct a balance study. For obvious reasons, it is impossible to feed only fats, and we have to conduct studies involving graded fat additions to a basal diet, with extrapolation of results to what would happen at the 100% feeding level. In these studies, we assume the difference in digestibility between any two diets is due solely to the fat added to the diet. If, because of synergism, the added fat improved digestibility of basal diet components, then this 'boost' in digestibility is attributed to the fat and an erroneously high value is projected. However, it can be argued that this 'boost' to fat's value occurs normally when fats are added to diets, and that these higher values more closely reflect the practical value of fat in a poultry diet. We have proposed this synergism to account for some of the so-called 'extra-caloric' effect of fat often seen in reported values, where metabolizable energy can sometimes be higher than corresponding gross energy values (which theoretically cannot occur). Table 2.10 shows results from this type of study where corn oil was assayed using different types of basal diet.

Table 2.10 Variation in ME value of corn oil attributed to fatty acid saturation of the basal diet

Basal diet	*Corn oil ME (kcal/kg)*
Predominantly unsaturated	*8390[a]*
Predominantly saturated	*9380[b]*
Corn-soy diet	*8510[a]*

When the basal diet contains saturated fatty acids, there is an apparent increase in the ME of corn oil. This effect is possibly due to the unsaturates in corn oil aiding in utilization of the basal diet saturates. However, because of methods of diet substitution and final ingredient ME calculation, any such synergism is attributed to the test ingredient (corn oil).

ME values of fats will therefore vary with inclusion level, although this effect will be influenced by degree of fat saturation. A ratio of 3:1, unsaturates:saturates is a good compromise for optimum fat digestibility for all ages of bird. However, this ratio may not be the most economical type of fat to use, because of the increased cost of unsaturates relative to saturates.

d. Level of Free Fatty Acids and Fatty Acid Hydrogenation

Concern is often raised about the level of free fatty acids in a fat, because it is assumed these are more prone to peroxidation. Acidulated soapstocks of various vegetable oils contain the highest levels of free fatty acids, which can reach 80 – 90% of the lipid material. For young birds there is an indication that absorption of fatty acids is highest in birds fed triglycerides rather than free fatty acids and this may relate to less efficient micelle formation or simply to less bile production. Wiseman and Salvadore (1991) demonstrated this effect in studying the ME value of tallow, palm oil and soy oil that contained various levels of free fatty acids (soapstock of the respective fat). Table 2.11 shows a summary of these results, indicating energy values for the respective fats containing the highest and lowest levels of free fatty acids used.

Table 2.11 Effect of level of free fatty acid and bird age on fat ME value (kcal/kg)

		Age	
		10 d	***54 d***
Tallow	*13% FFA*	*7460*	*7940*
	95% FFA	*4920*	*6830*
Palm	*6% FFA*	*6690*	*7800*
	92% FFA	*3570*	*6640*
Soy	*14% FFA*	*9290*	*9300*
	68% FFA	*8000*	*8480*

Adapted from Wiseman and Salvador (1991)

These data suggest that free fatty acids are more problematic when the fat is predominantly saturated and this is fed to young birds. Contrary to these results, others have shown comparable results with broilers grown to market weight and fed tallows of varying free fatty acid content.

Hydrogenation of fats becomes an issue with the general use of these fats in restaurants, and the fact that restaurant grease is now a common, and sometimes the major component of feed-grade fat blends. Hydrogenation results in a high level of trans oleic acid (40 – 50%) and such vegetable oils have physical characteristics similar to those of lard. There seems to be no problem in utilization of these hydrogenated fats by poultry with ME values of restaurant greases being comparable to those of vegetable oils. The long-term effect of birds eating trans fatty acids is unknown at this time.

e. Bird Age and Bird Type

Young birds are less able to digest saturated fats, and this concept has been known for some time. With tallow, for example, palmitic acid digestibility increases from 50 to 85% through 14 to 56 d of age, which together with corresponding changes for other fatty acids means that tallow ME will increase by about 10% over this time period. The reason why young birds are less able to digest saturated fats is not well understood, although it may relate to less bile salt production, less efficient recirculation of bile salt or less production of fatty acid binding protein.

f. Soap Formation

When fats have been digested, free fatty acids have the opportunity of reacting with other nutrients. One such possible association is with minerals to form soaps that may or may not be soluble. If insoluble soaps are formed, there is the possibility that both the fatty acid and the mineral will be unavailable to the bird. There is substantial soap formation in the digesta of broiler chicks and this is most pronounced with saturated fatty acids, and with increased levels of diet minerals. Such increased soap production is associated with reduced bone ash and bone calcium content of broilers. Soap production seems to be less of a problem with older birds. This is of importance to laying hens that are fed high levels of calcium. In addition to calcium, other minerals such as magnesium can form soaps with saturated fatty acids. In older birds and some other animals, there is an indication that while soaps form in the upper digestive tract, they are subsequently solubilized in the lower tract due to changes in pH. Under these conditions both the fatty acid and mineral are available to the bird. Control over digesta pH may, therefore, be an important parameter for control over soap formation.

g. Variable ME Values

It seems obvious that the use of a single value for fat ME during formulation is a compromise, considering the foregoing discussion on factors such as inclusion level, bird age, soap formation etc. Table 2.8 gives different ME values for birds younger or older than 21 d, and this in itself is a compromise. Following is an attempt to rationalize the major factors affecting ME of a given fat, although it is realized that such variables are not easily incorporated within a formulation matrix (Table 2.12).

Table 2.12 Factors affecting fat ME values

		Relative fat ME
Bird age:	*28 d+*	*100%*
	7 - 28 d	*95%*
	1 – 7 d	*88%*
		(esp. for saturates)
Free fatty acids:	*0 – 10%*	*102%*
	10 – 20%	*100%*
	20 – 30%	*96%*
	30%+	*92%*
		(esp. for saturates)
Inclusion level:	*1%*	*100%*
	2%	*100%*
	3%	*98%*
	4%	*96%*
	5%+	*94%*
Calcium level:	*<1%*	*100%*
	>1%	*96%*
		(esp. for birds <56 d of age)

h. Trans Fatty Acids

Trans fatty acids are isomers of naturally occurring cis fatty acids. Trans fatty acids are often produced by the process of hydrogenation, as commonly occurs in production of margarine and other cooking fats. Hydrogenated (stabilized) soybean oil, which is a common component of cooking oils, contains around 20% trans fatty acids. With increasing use of restaurant grease in animal fats and fat blends, it seems inevitable that fats used in the feed industry will contain higher proportions of trans fatty acids than occurred some 20 years ago. It is thought that 'overused' frying oil, that contains trans fatty acids as well as oxidized and polymerized materials, is harmful to human health. These trans fatty acids can be found in human adipose tissue, and have been associated with immune dysfunction and unusual lipid metabolism in heart tissue. There is very little information available on the effect of trans fatty acids on health of broilers or layers.

OTHER INGREDIENTS

20. Oats

Oats are grown in cooler moist climates although they are of minor importance on a global scale, representing only about 1.5% of total cereal production. Most oats are used for animal feed, and about 85% of this quantity is used locally and there is little trade involved. The hull represents about 20% of the grain by weight, and so this dictates the high fiber – low energy characteristics of oats. The amino acid profile is however quite good, although there is some variation in protein and amino acid levels due to varietal and seasonal effects. The best predictor of the energy value of oats, is simply the crude fiber content which is negatively correlated with ME. Oat lipids are predominantly oleic and linoleic acid, although a relatively high proportion of palmitic acid leads to a 'harder' fat being deposited it the bird's carcass.

As for other small grains, oats contain an appreciable quantity of ß-glucans, and these cause problems with digesta and excreta viscosity. Most oats contain about 3-7% ß-glucans and so with moderate inclusion levels of oats in a poultry diet it may be advantageous to use supplemental ß-glucanase enzyme. There has been some interest in development of so-called naked oats, which are similar in composition to oat groats. Naked oats contain up to 17% CP with 0.68% lysine and 1% methionine plus cystine. The ME value is around 3200 kcal/kg, making these oats comparable to wheat in most characteristics. As with regular oats, ß-glucans can still be problematic and their adverse effect can be overcome with use of exogenous enzymes, and to a lesser extent antibiotics such as neomycin. Much of the phosphorus in naked oats is as phytic acid, and so availability is very low. There have been some reports of reduced skeletal integrity in birds fed naked oats unless this reduced phosphorus availability is taken into account. There are reports of broilers performing well with diets containing up to 40% naked oats, and with layers, up to 50% has been used successfully.

21. Rye

Although the nutrient content of rye is essentially similar to that of wheat and corn, its feeding value for poultry is poor due to the presence of various antinutritional factors. Rye contains a water insoluble fraction, which if extracted, improves its feeding value. Various other treatments such as water soaking, pelleting, irradiation and the dietary supplementation of various antibiotics all help to improve the growth of chicks fed rye.

One of the most noticeable effects of feeding rye, other than reduced performance is the production of a very sticky and wet excreta. The sticky droppings are due to the pectin-like components present in rye. Structural arabinoxylans, present in rye endosperm cell walls, are responsible for creating the viscous digesta. These viscous products reduce the rate of diffusion of other solutes in the digesta so affecting nutrient uptake from the gut. In recent years enzyme preparations have been developed that markedly reduce the antinutritional factor and eliminate the wet-sticky fecal problem with rye based diets.

22. *Triticale*

Triticale is a synthetic small grain cereal resulting from the intergeneric cross of wheat and rye. Its higher yield per acre, as compared to rye or wheat, make it of agronomic interest in areas of the world not suitable for corn production. Numerous cultivars have been developed with protein contents varying from 11 to 20% and amino acid balance comparable to wheat and superior to that of rye. Energy content is also similar to that of wheat and superior to that of rye. Like wheat, triticale has a significant phytase content and so is a better source of available phosphorus than other cereals such as corn or milo. There are reports of increased enhancement of other dietary phosphorus with triticale supplementation. The starch content of triticale is as digestible as that of wheat and presents no wet litter or sticky manure problem. Where triticale is available, high levels can be used in poultry diets without any adverse problems. Similar to wheat and rye it contains little or no xanthophylls and with fine grinding can result in beak impaction with young birds. Also like wheat its feeding value can be increased by appropriate enzyme supplementation of the diet.

23. *Molasses*

Molasses is a by-product of the sugar refining industry, where either sugar beet or sugar cane are used as raw materials. Because of a high water content and concomitantly low energy value, it is only used extensively in poultry diets in areas close to sugar refineries. The molasses usually available for animal feeding is so called final or blackstrap molasses, which is the product remaining after most of the sugar has been extracted for human consumption. Depending upon local conditions, high-test and type A and B molasses are sometimes available. The high-test product is basically unrefined cane or beet juice that has had its sugars inverted to prevent crystallization. Type A and B molasses are intermediate to final molasses. As expected, the energy level of molasses decreases as more and more sugar is extracted. Molasses is usually quantitated with a Brix number, measured in degrees, and these numbers relate very closely to the sucrose concentration in the product. Both cane and beet molasses contain about 46 - 48% sugar.

Although molasses contains relatively little energy and protein, it can be used to advantage to stimulate appetite and to reduce dustiness of feed. For example, feed intake is usually increased in birds such as young Leghorn pullets, if molasses is poured directly onto feed in the feed trough. It is doubtful that molasses improves 'taste' of feed under these conditions, rather it presents a novel feed texture to the bird. A major problem with molasses is a very high potassium content, at 2.5 – 3.5%, which has a laxative effect on birds. While most birds perform well on balanced diets containing up to 2% molasses, inclusion levels much above 4% will likely result in increased water intake and increased manure wetness.

24. Dehydrated Alfalfa

Dehydrated alfalfa meal can be quite high in protein (18 – 20%) although because the product is heated during drying, availability of essential amino acids such as lysine is often 10 to a 20% below expected values. Alfalfa is very high in fiber content, and is most often added to poultry diets as a source of xanthophylls for pigmentation, or as a source of so-called unidentified growth factors.

Alfalfa products should contain a minimum of 200,000 IU vitamin A activity per kg, although in most cases this will only be 70% available. In order to achieve intense yellow skin color in broilers or egg yolk color of □ 10 on the Roche scale, diets should contain 5% alfalfa as one source of xanthophylls in the diet. Alfalfa levels much in excess of 5% have only a moderate effect on pigmentation and so other natural or synthetic sources must be used to ensure consistently high levels of pigmentation. At high levels of inclusion (20%) problems can arise due to the saponins and phenolic acids normally present in alfalfa. If alfalfa contains any appreciable mold count, then estrogen level can be high. Fresh grass is thought by some nutritionists to contain an unidentified growth factor which is of particular significance to turkeys, although much of this factor is destroyed by the dehydrating process. Even so, many nutritionists still insist on adding 1 – 2% dehydrated alfalfa to turkey feeds, especially pre-starter and starter diets. The addition of small quantities of alfalfa also impart a darker color to diets which helps mask any minor fluctuations in appearance due to regular changes in formulations. The quality of alfalfa products has been improved considerably in recent years due to the use of inert gas storage, pelleting and addition of antioxidants.

25. Full-fat Canola Seeds

The nutrient profile of canola seed makes it an ideal ingredient for high nutrient dense diets. Periodically, grades unfit for oil extraction are available for animal feeding. Canola seed suffers from the same problems as described for canola meal, although obviously most harmful elements are diluted by the high oil content. Seeds must be ground adequately to ensure normal digestion, and this is best accomplished by mixing with ground corn prior to passing through a hammer mill. The oil provides considerable energy, and is an excellent source of linoleic acid. The ground seed is not too oily, and so provides a practical way of adding considerable quantities of fat to a diet. Due to early frost damage, some samples of canola contain oil that is contaminated with chlorophyll – while unacceptable to the human food industry, this contaminant does not seem to pose any major problems to poultry.

26. Groundnut (Peanut) Meal

The peanut is an underground legume, and because of warm moist conditions in the soil, is very susceptible to fungal growth with aspergillus contamination being of most concern. Grown essentially for their oil, peanuts yield a solvent extracted meal containing 0.5 – 1% fat with about 47% protein. As with soybeans, peanuts contain a trypsin inhibitor that is destroyed by the heating imposed during oil extraction. Potential aflatoxin contamination is the major problem with groundnut meal. Being a potent carcinogen, aflatoxin causes rapid destruction of the liver, even at moderate levels of inclusion. Peanut meal that is contaminated with aflatoxin can be treated by ammoniation which seems to remove up to 95% of the toxin. Alternatively, products such as sodium-calcium aluminosilicates can be added to the diet containing contaminated groundnut because these minerals bind with aflatoxin preventing its absorption.

27. Peas

Peas are a medium energy-protein ingredient that can be used effectively in poultry diets depending upon local economical conditions. The major limitation to using peas is low levels of sulfur amino acids and moderate energy level. With high-tannin peas, there may be an advantage to some type of heat treatment, although such processing is of little value for regular pea varieties. Protein digestibility is reduced by about 6% for each 1% increase in tannin content. Peas do have some of their carbohydrate as oligosaccharides, and so enzyme systems being developed to improve the digestibility of soybean meal may be of use with peas. Peameal is a very dense material and bulk density of the final diet should be taken into consideration for diets containing > 15% peas.

28. Safflower

Safflower is grown mainly for its oil content which, although variable, can be as high as 40%. The residual meal contains in excess of 20% fiber and is referred to as undecorticated safflower meal. It is possible to commercially remove a large portion of the hull resulting in a meal containing 42 to 44% protein with a fiber content of around 14%. This product is referred to as decorticated meal. Safflower meal is very deficient in lysine, although with appropriate lysine supplementation the protein quality of safflower meal is similar to that of soybean meal. However, with the high fiber content the available energy is still relatively low and so its value does not equal that of soybean meal. Where safflower meal is available, relatively large quantities can be used in poultry diets if proper consideration is given to nutrient availability.

29. Sesame Meal

Sesame meal is very deficient in available lysine, and this is sometimes used to advantage in formulating lysine-deficient diets for experimental reasons. Sesame also contains high levels of phytic acid which can cause problems with calcium metabolism leading to skeletal disorders or poor eggshell quality. If diets contain >10% sesame, then the diet should be formulated to contain an extra 0.2% calcium.

30. Lupins

Low alkaloid lupins are being increasingly used as an alternative feedstuff for poultry in certain areas of the world. These new cultivars have been reported to contain low levels of the toxic alkaloids (less than .01%) normally found in wild varieties. These low alkaloid lupin seeds are often referred to as sweet lupins and can vary in seed color. The high level of fiber in the seeds (up to 25%) results in low metabolizable energy values compared to soybean meal. Mature lupin seeds contain little or no starch, the bulk of their carbohydrate being oligosaccharides (sugars) and non-starch polysaccharides. Many reports suggest that sweet lupins are comparable to soybeans in terms of protein quality although they are much lower in methionine and lysine. Their low oil content (6 to 10%) and absence of antinutritive factors means that they can be inexpensively processed. Recent studies have shown that dehulling lupins results in a marked increase in nutritive value. Also with proper dietary enzyme supplement the feeding value of raw lupins is improved. Fine grinding also aids digestibility.

31. Blood Meal

Blood meal is very high in crude protein, and while it is an excellent source of lysine, it is very deficient in isoleucine and this imbalance needs correcting if any substantial quantity is used in a diet. Blood meal is essentially the solids of the blood from processing plants, and consists mainly of hemoglobin, cell membranes, cellular electrolytes and a small quantity of lipid.

Historically, the level of blood meal used in diets has been severely limited, mainly because of problems of palatability, poor growth rate and abnormal feathering. All these problems relate to inherent amino acid balance and also to low digestibility induced by overheating of the blood during processing. With less harsh drying treatments, the amino acids are more stable, and there are few problems with palatability. If blood meal is overheated, it has a much darker color, tending to be black rather than reddish-brown. The amino acid balance of blood meal can be 'improved' by combining it with other ingredients. For example, a 50:50 mixture of blood meal and hydrolyzed hair meal gives a product with a reasonable amino acid balance, and certainly a balance that is preferable to either product alone. Such a mixture may be used in least-cost formulation, whereas either ingredient is unlikely to be used independently because of amino acid balance.

32. Sources of Calcium, Phosphorus and Sodium

Calcium

Constraints are not usually imposed on these ingredients because there should be fairly stringent constraints imposed on minimum and maximum levels of calcium and phosphorus in a diet. There has been considerable controversy in the past concerning the relative potency of limestone vs oyster shell as sources of calcium, especially for the laying hen. Perhaps of more importance than the source of calcium, is particle size. Usually the larger the particle size, the longer the particle will be retained in the upper digestive tract. This means that the larger particles of calcium are released more slowly, and this may be important for the continuity of shell formation, especially in the dark period when birds are reluctant to eat. Oyster shell is a much more expensive ingredient than limestone, but it offers the advantage of being clearly visible in the diet to the egg producer and so there is less chance of omission during feed manufacture. Birds also have some opportunity at diet self-selection if oyster shell is given, and this may be of importance in maintaining optimum calcium balance on egg-forming vs non egg-forming days. There are current limitations on oystershell dredging in the Chesapeake region of the U.S.A., due to environmental issues, and this may add to the discrepency in price between oystershell and limestone.

Limestone should be in as large a particle size as can be readily manipulated by the bird's beak. For laying hens, this means a fairly coarse crumble consistency. There has been some concern in recent years regarding the variability in solubility of limestone from various sources. This can easily be checked by measuring pH changes when limestone is added to hydrochloric acid at initial pH of 4.0. Obviously 100% solubility is desirable, yet ideally this should be achieved over a prolonged period of time which hopefully correlates with the slow release of calcium into the blood stream.

Periodically, dolomitic limestone is offered to the feed industry. Dolomitic limestone contains at least 10% magnesium, and this complexes with calcium or competes with calcium for absorption sites. The consequence of feeding dolomitic limestone is induced calcium deficiency, usually manifested by poor skeletal growth or egg shell quality. The major user of dolomitic limestone is the steel industry and so problems with this ingredient seem to mirror the economic malaise in steel production. Dolomitic limestone should never be used in poultry diets.

Phosphorus

A considerable number of inorganic phosphorus sources are used around the world.

Most naturally occurring phosphate sources are unavailable to the bird unless they are heat-treated during processing. As with limestone, the solubility in HCl at pH 4 can be used as a measure of quality. Insoluble phosphate sources are unlikely to be available to the bird – however solubility is not a guarantee of subsequent availability. Solubility tests are therefore only useful in screening out insoluble sources. Tests for biological availability are much more complex, because they necessarily require a chick bioassay where growth and bone ash are measured.

The phosphorus in most phosphate sources with the exception of soft phosphate, can be regarded as close to 100% available. Rock phosphate and Curaco phosphate are the major exceptions because these sources may only be 60 – 65% available to the bird. Anhydrous dicalcium phosphate is about 10% less available than the hydrated form, and this seems to relate to solubility. In this context, ingredients that stimulate gastric secretion, and hence HCl production, seem to result in improved utilization of the anhydrous form. Some rock phosphates contain various contaminants of concern for poultry. The most common of these is vanadium. At just 7 – 10 ppm of the diet, vanadium will cause loss in internal egg quality and hatchability. At slightly higher levels (15 – 20 ppm), there is a change in the shell structure where the shell takes on a somewhat translucent appearance, and appears more brittle. Rock phosphates can also contain as much as 1.5% fluorine. Because fluorine can influence calcium metabolism, there are often regulations governing the maximum permissible levels in feed. Only defluorinated rock phosphates are recommended although it must be remembered that this product usually contains about 5% sodium. Most mineral sources are detrimental to the pelleting process because they create significant friction at the pellet die. With phosphates, there is a distinct advantage to using rock phosphates rather than mono- or dicalcium phosphate in terms of pelleting efficiency, where up to +10% throughput is achieved.

Sodium Sources

Most diets will contain some added salt, usually in the form of sodium chloride. Where iodine is not added as a separate ingredient, iodized salt must be used. In most countries the various salt forms are differentiated by color, with common salt being a natural white color and iodized salt being red. Cobalt iodized salt is often used in diets for swine and ruminants, and this can be used without any problems for poultry. This type of salt is usually colored blue. Because high levels of sodium chloride can lead to increased water intake, then a substitution of sodium bicarbonate for a portion of this chloride salt has been shown to be beneficial. Under these condition, up to 30% of the supplemental salt can be substituted with sodium bicarbonate without loss in performance, and such birds often produce drier manure. For substitutions of sodium bicarbonate for sodium chloride above 30%, care must be taken to balance dietary chloride levels, since under commercial conditions it is often difficult to add inexpensive sources of chloride other than salt. Chloride contributed by ingredients such as choline chloride and lysine-HCl should be accommodated during formulation. There is a trade-off when substituting sodium bicarbonate for sodium chloride under heat-stress conditions. Birds will drink less when $NaHCO_3$ is used, and this is the reason for substitution. However, we really have to question this scenario, since higher levels of water intake are correlated with survival under extreme heat stress conditions. Sources of calcium, phosphorus and sodium are given in Table 2.13.

Table 2.13 Calcium, phosphorus and sodium sources

Ingredient	*% Ca*	*% P*
Limestone	*38.0*	*-*
Oyster shell	*38.0*	*-*
Calcium carbonate	*40.0*	*-*
Bone meal	*26.0*	*13.0*
Monocalcium phosphate	*17.0*	*25.0*
Dicalcium phosphate	*21.0*	*20.0*
Tricalcium phosphate	*23.0*	*19.0*
Defluorinated rock phosphate	*34.0*	*19.0*
Curaco phosphate	*35.0*	*16.0*
Phosphoric acid (75%)	*-*	*25.0*

Ingredient	*% Na*	*% Cl*
Plain salt	*39.0*	*60.0*
Iodized salt	*39.0*	*60.0 (I, 70 mg/kg)*
Cobalt iodized salt	*39.0*	*60.0 (I, 70 mg/kg; Co, 40 mg/kg)*
Sodium bicarbonate	*27.0*	*-*

33. Trace Minerals

Trace minerals are available in a variety of forms, and periodically problems arise due to lack of knowledge of the composition, and/or stability of mineral salts. Most research into mineral availability has been conducted with so-called reagent-grade forms of minerals, which are very pure and of known composition and purity. Unfortunately, the feed industry cannot afford the luxury of such purity, and so obviously, feed grade forms are used.

One of the most important factors to ascertain prior to formulation is the state of hydration of a mineral. Many mineral forms contain 'bound' water which obviously dilutes the effective mineral concentration. For example, hydrated cupric sulphate (white crystal) contains about 40% copper, whereas the more common pentahydrate (blue) contains 26% copper. It should also be emphasized that the various processing conditions used in manufacturing will likely influence mineral bioavailability. A combination of these two factors can mean a substantially lower potency of trace mineral sources relative to chemical standard values (Table 2.14). For this reason, feed manufacturers are encouraged to take great

Table 2.14 Trace mineral sources

	Ingredient	% of major mineral		Ingredient	% of major mineral
Cobalt	oxide	71.0	Manganese	oxide	77.0
	chloride	24.0		chloride	27.5
	sulphate	21.0		sulphate	32.5
	carbonate	46.0		carbonate	47.0
Copper	oxide[1]	79.0	Zinc	oxide	78.0
	chloride	37.0		chloride	48.0
	sulphate	25.5		sulphate	36.0
	carbonate	55.0		carbonate	52.0
Iron	oxide[2]	77.0	Selenium	sodium selenite	46.0
	chloride[3]	34.0		sodium selenate	42.0
	sulphate[2]	32.0	Iodine	potassium iodine	77.0
	carbonate[2]	40.0		calcium iodate	65.0
Magnesium	oxide	56.0			
	carbonate	30.0			

[1] Cupric; [2] Ferrous; [3] Ferric

care in ordering trace minerals based on valency, hydration and purity. All minerals sources should be analyzed, on an 'as is' basis for the major mineral component.

Because feed manufacturers are often concerned about 'space' in the diet during formulation, there is a trend towards making very concentrated mineral and vitamin premixes. In considering concentration of mineral sources, oxides appear attractive, since they invariably contain the highest mineral concentration. Oxides however, are potent oxidizing agents, and if stored with premixed vitamins for any length of time, can cause the destruction of vitamins that are susceptible to oxidation. Since oxides are generally less available than other mineral salts, they should not be used exclusively in mineral premixes.

Cobalt

The major source of cobalt is cobalt sulphate or cobalt carbonate. Both products are good sources of cobalt, with the cobalt as sulphate being slightly more available than in the carbonate form. Cobalt oxide has very low availability, and should not usually be considered during formulation.

Copper

Copper oxide, sulphate and carbonate are used by the feed industry. Copper oxide can be of very low biological availability, especially with poor quality samples that contain significant amounts of metallic copper. Good quality copper oxide can be considered as available as is copper sulphate. As previously mentioned, the degree of hydration of copper sulphate must be specified.

Iron

Ferrous salts should be used in feed manufacture. As with copper, the major contaminant can be the metal itself, and this has a very low biological availability. Ferrous carbonate and ferrous sulphate are the preferred forms of iron. Ferrous salts are prone to chemical change during storage, such that 10 – 20% of ferric salts can be produced from original ferrous forms after 3 –6 months storage at around 25ºC.

Magnesium

Magnesium carbonate and oxide are both available in feed grade form. The oxide can take up both water and carbon dioxide when stored for any length of time, and such activity obviously reduces the relative potency of magnesium.

Manganese

The major source of manganese used in the feed industry is manganese oxide. Sulphate and carbonate sources both have higher biological availability, yet these are usually uneconomical to use. Manganese oxide has a biological availability of 50 – 70%, yet this can be greatly influenced by its major contaminant, namely manganese dioxide. Manganese dioxide is only 50% as bioavailable as is the oxide, and so an appreciable content of dioxide can lead to a marked reduction in effectiveness of manganese oxide. Oxides should not contain more than 10% dioxides, and undoubtedly the range of availability quoted in research findings is usually a reflection of dioxide contamination.

Zinc

Zinc oxide and zinc sulphate are the most common forms of zinc used in the feed industry. Zinc is often used as a catalyst in various industrial processes, and unfortunately catalysts sometimes find their way into the feed industry and are of low biological availability. Zinc sources can be contaminated with aluminum, lead and cadmium. If good quality sources are considered, then zinc oxide and zinc sulphate appear to be of comparable biological availability.

Selenium

Selenium is most often added to feeds as sodium selenite or sodium selenate. The most common naturally occurring form of selenium is selenomethionine, and this seems to have a much lower potency than either of the salt forms. There seems to be a greater availability of selenium within low protein diets, although this may be related to the fact that when birds are growing at a slower rate, their absolute selenium requirement is reduced. Selenium availability, from whatever source, is improved when diets contain antioxidants.

Selenite is more readily reduced to elemental selenium, and for this reason selenate is sometimes preferred. Selenium metal is less available and can form insoluble complexes with other minerals. Whichever form of selenium is used, it must be remembered that the final diet inclusions are extremely low in relation to the other minerals, and so some degree of premixing is essential prior to incorporation in diets or premixes.

Iodine

If iodine is added to a mineral premix, rather than supplied with salt, then potassium iodide and calcium iodate are the preferred sources. Potassium iodide is very unstable and deteriorates rapidly with moderate exposure to heat, light and/or moisture. Calcium iodate is the most common source of supplemental iodine.

Mineral chelates

Chelates are mixtures of mineral elements bonded to some type of carrier such as an amino acid or polysaccharide. These carriers, or ligands, have the ability to bind the metal,

usually by covalent bonding through amino groups or oxygen. The formed chelate is usually a ring structure with the divalent or multivalent metal held strongly or weakly through two or more covalent bonds. Iron in hemoglobin is the classical example of a chelate. The covalent bonding is such that the chelate has no electrical charge.

Chelated, or complexed minerals are usually much more expensive than inorganic minerals, and so one expects improved bird performance through either enhanced absorption or better utilization in some way. It is difficult to rationalize the cost of chelated minerals based solely on improved absorption in the intestine. Even a 50% difference in absorption can be most economically resolved by doubling the level of inorganic mineral used. However, there are limits to the level of any one mineral to be used, because of potential negative effects of absorption and utilization of other minerals and other nutrients. The mineral availability from some inorganic sources can be very low. For example, the manganese in some samples of manganese sulfate has been reported at just 5%, and in this instance a 20 fold increase in inclusion level, while correcting the potential manganese absorption problem, will likely have adverse effects on utilization of phosphorus, calcium and iron.

Factors affecting the uptake of heme iron are often used to support the concept of using chelated minerals. There are a number of other trace minerals, such as copper, manganese and phosphorus that can affect absorption of inorganic iron, while uptake of heme iron will be little affected. The uptake of chelated minerals is therefore expected to be more consistent and less affected by adverse (or enhanced) environments in the gut lumen. Bioavailability of minerals from chelates should also be consistent because of standardization during manufacture versus less standard conditions with some supplies of inorganic salts. There are also claims of chelated minerals being used more effectively at the cellular level following absorption. There are few classical supporting claims for these suppositions, and so enhanced performance of meat birds and layers is discussed in terms of stimulation of various biological processes by the mineral and/or that the chelated mineral enters certain pools with greater affinity or efficiency.

Inorganic minerals are likely to contain trace quantities of heavy metals such as arsenic, lead and cadmium. Such levels of heavy metals are not problematic to poultry, although the EEC has recently imposed limits of these metals in mineral premixes and complete feeds. While it is challenging to consistently achieve minimum levels using conventional mineral salts, most chelated minerals are very pure and usually contain no heavy metals.

Ultimately the choice of using inorganic versus chelated minerals is one of economics, which obviously relates to cost benefit. Such results may vary depending upon the levels and spectrum of trace minerals used and the bioavailability to be expected from inorganic sources that are available.

34. Synthetic Amino Acids

Synthetic sources of methionine and lysine are now used routinely in poultry diets and tryptophan and threonine will likely be used more frequently as future prices decline. In most situations, the use of synthetic amino acids (Table 2.15) is an economic decision, and so their price tends to shadow that of soybean meal, which is the major protein (amino acid) source used world-wide. By the year 2010, lysine use in North America is estimated to be at 150,000 tonnes while that for methionine will be around 85,000 tonnes, of which the poultry industries use 30 – 65%.

Table 2.15 Synthetic amino acids

Amino acid	*Relative activity* (%)	*Crude protein equivalent*
DL-Methionine	100	59
Methionine hydroxy analogue (liquid)	88	0
L-Lysine	100	120
L-Lysine HCL	79	96
L-Arginine	100	200
L-Arginine HCL	83	166
L-Tryptophan	100	86
L-Threonine	100	74
Glycine	100	117
Glutamic acid	100	117

Lysine is usually produced as the hydrochloride salt, and consequently, the commercial products have 79% lysine activity on a weight basis. Liquid lysine products are now also available. In North America, lysine tends to be considered a commodity, and as such its use is directly related to that of other ingredients. In general, there is greater L-lysine HCl usage when soybean meal price increases, or when corn price declines. In Europe however, because of inherently higher commodity prices, L-lysine HCl tends to be used less as a commodity, and more as a means of improving performance. Care must be taken therefore, in interpretation of cost benefit of lysine use in research results reported from these two regions.

Tryptophan is not usually a limiting amino acid in most poultry diets, and so the move to greater synthetic tryptophan use comes from the swine industry. Tryptophan will become a limiting nutrient as crude protein levels of diets are reduced, although currently its efficient use is somewhat hampered by complexity involved in diet analysis. Tryptophan levels in ingredients and feed are much more difficult to assay than are the other common amino acids, and in part, this situation leads to variability in research results aimed at quantitating response to tryptophan. This amino acid is most likely to be considered when diets contain appreciable quantities of meat or poultry by-product meal.

Methionine is available in a number of forms and also as an analogue. Over the years there has been considerable research into the potency and use of these various sources. There are essentially four different sources of methionine (Table 2.16).

Table 2.16 Methionine sources

DL-methionine	*DL-methionine Na*	*Methionine hydroxy analogue*	*Methionine hydroxy analogue-Ca*
CH_3	*CH_3*	*CH_3*	*CH_3*
S	*S*	*S*	*S*
CH_2	*CH_2*	*CH_2*	*CH_2*
CH2	*CH_2*	*CH_2*	*CH_2*
H-C-NH_2	*H-C-NH_2*	*H-C-OH*	*H-C-OH*
COOH	*$COONa^+$*	*COOH*	*$COOCa^+$*
Powder	*Liquid*	*Liquid*	*Powder*

Dow Chemical was the first to produce powdered DL-methionine in commercial quantities in the 1940's, while Monsanto introduced the calcium salt of methionine hydroxy analogue in the 1950's. Since this time, the market has established demand for both DL-methionine and the analogue, in both powdered and liquid forms.

It has been known for some time that most essential amino acids can be replaced by the corresponding α-keto acid (analogue). With the exception of lysine and threonine, which are not involved in transamination processes, it is therefore possible to replace amino acids with their keto acid-analogues. Presumably the bird produces the corresponding amino acid by transamination involving mainly non-essential amino acids such as glutamic acid. Such transamination can occur in various tissues, and some bacteria in the intestine may also synthesize amino acids prior to absorption. The question of relative potency of products such as liquid MHA (eg. Alimet®) often arises in selection of methionine sources. Liquid MHA has a value of 88% methionine based on normal chemical structure. Availability of this 88% value has then been shown to vary from 60 – 100%. It seems inconceivable that any nutrient could have such variable efficacy, and so one must look at experimental conditions and diet formulation in assessing such results. Potency of MHA relates to variable uptake in the intestine, degradation in body tissues and/or degree of elimination by the kidney. Another major variable in response to MHA under commercial conditions is ingredient methionine levels used in formulation and diet specifications for methionine and cystine. There are usually logical reasons why nutritionists use different potency values. The bottom line is cost per kg of meat/eggs produced, and the value of products such as MHA quickly establish themselves over time within an integrated operation. In most situations MHA is used at 85-88% relative to DL-methionine.

2.2 INGREDIENT TESTING

Ingredients must be continuously monitored to ensure consistency of nutrient profile and presence of potential contaminants. The number and frequency of assays will depend upon the class of ingredient, historical results of analysis and to some extent the season of the year. Ingredients from new suppliers should be tested the most rigorously, and number and frequency of testing reduced only when consistency of nutrient profile is established. Examples of the type and frequency of testing are given previously with the description of all the major ingredients.

The frequency of sampling will obviously vary with the significance of a particular ingredient in the feed. For example, where fish meal is used extensively, and represents a significant proportion of dietary amino acids, then amino acid analyses may be done more frequently, and it may also be advisable to screen more often for gizzard erosion factors. On the other hand, where a history of consistent analyses is developed, then testing can be less frequent.

For assay results to be meaningful, ingredients must be sampled accurately. For bagged ingredients, at least 4 bags per tonne, to a maximum of 20 samples per delivery, should be taken, and then these sub-samples pooled to give one or two samples that are sent for assay. It is always advisable to retain a portion of this mixed sample, especially when assays are conducted by outside laboratories. For bulk ingredients, there should be about 10 sub-samples taken from each truck or rail car load and again this mixed to give a representative composite for assay.

There are a number of rapid tests available for evaluating ingredients. In some instances, these tests are specific to certain ingredients and to specific nutrients and/or antinutrients within an ingredient. Alternatively, some tests are more generic and can be applied across a number of ingredients. The decision to carry out any of these tests is based on significance of the ingredient in the diet, and so the relative contribution of constituents under test. Developing historical data on ingredients is also a useful way of determining the need and frequency of various testing procedures. The following tests or methodologies are assumed to be in addition to more extensive chemical testing that will routinely be used for the most important nutrients.

a. Bulk density

Bulk density of individual cereals is correlated with energy value and protein content. In North America, the usual measurement is bushel weight, while the common metric equivalent is kg/hl. Weight of 100 kernels of cereal is also used as an indicator of bulk density. Under normal growing conditions, as bulk density declines, there is usually a reduction in energy level, mainly associated with reduction in starch content of the endosperm. Concurrently protein content often increases since protein is commonly found in the outer bran or pericarp layers. Bulk density is also a useful measure for calculation of needs for storage space within the mill.

Bulk density will vary with moisture content, and this should be taken into account during measurement. Density is easily measured by weighing the cereal or feed into a container of known volume. The smaller the container, the greater the care needed in standardizing the filling and especially the packing of the ingredient. Bulk density values are not always

additive and so the density of a mash feed cannot always be predicted from knowledge of bulk density of component ingredients. This situation arises, because of 'mixing' of particles of different size within a feed, so affecting the empty space common with low bulk density ingredients such as wheat shorts or alfalfa meal.

b. Proximate analysis

Proximate analysis is still the most widely used system for monitoring the quality of ingredients. At a time when we formulate diets based on digestible or metabolizable nutrients, its value is often questioned, since proximate components are very broad and encompass what can be both digestible and indigestible components. However, proximate analysis is quite rapid and inexpensive, and does give an idea of continuity of composition. Proximate analyses can also be used to predict the content of nutrients such as total and digestible amino acids. This type of information is essentially regression analyses of simple proximate components versus analytical values for amino acids.

For proximate analysis an ingredient is partitioned into six fractions, namely water, ether extract, crude fiber, nitrogen-free extract, crude protein and ash. Some of the information from proximate analyses (usually the protein, ether extract, fiber and ash values) are shown on descriptive feed labels, which accompany feedstuffs and complete feeds. These values represent the guarantees of quality used by the feed manufacturing industry.

Water is usually determined by the loss in weight that occurs in a sample upon drying to constant weight in an oven. Although water is considered a nutrient, it effectively is a diluent for other nutrients. Increase in moisture, therefore, reduces the total nutritional value of a feedstuff. Because water content can vary, ingredients should be compared for their nutrient content on a dry matter basis. Moisture much in excess of 12 – 13% is cause for concern regarding potential for mold growth.

Fat is determined by extracting the dry sample with ether. The weight of the extract is determined after distilling the ether and weighing the residue. Although this is the usual method for determining fat in feeds, ether extraction does not remove all the fats, especially phospholipids or fats bound to protein. Often acid hydrolysis followed by extraction of the hydrolysate with chloroform:methanol or ether is necessary to obtain 'total' lipid values. Acid hydrolysis also liberates fat present as soap, and is more likely to liberate fat from bacterial cell walls.

Crude protein is determined by measuring the nitrogen content of the feed and multiplying this by 6.25. This factor is based upon the fact that on average, a pure protein contains 16% nitrogen. Thus 100/16 = 6.25. For most ingredients, this assumption is fairly accurate, and allows us to estimate protein (which is a very complex assay) based simply on assay for nitrogen, which is quite straightforward and inexpensive. The nitrogen content of a feedstuff is determined usually by the Kjeldahl or heco methods. The Kjeldahl involves conversion of the nitrogen in feedstuffs to an ammonium salt by digestion with concentrated sulfuric acid in the presence of a suitable catalyst. The ammonia is distilled from the digestion mixture into a collecting vessel after the sample is made alkaline. The amount of ammonia is determined by titration with standard acid, and then nitrogen, and hence crude protein are calculated.

Ashing of an ingredient combusts all organic constituents, leaving behind only the mineral elements. Some elements such as selenium and arsenic form volatile oxides at this temperature. These losses can be avoided if the ash is made alkaline by addition of known quantities of calcium oxide prior to ashing.

Crude fiber refers to the organic residue of a feed that is insoluble after successive boiling with H_2SO_4 and NaOH solutions according to specified procedures. The determination of crude fiber is an attempt to separate the more readily digestible carbohydrates from those less readily digestible. Boiling with dilute acid and alkali is an attempt to imitate the process that occurs in the digestive tract. This procedure is based on the supposition that carbohydrates, which are readily dissolved by this procedure, also will be readily digested by animals, and that those not soluble under these conditions are not readily digested. At best, this is an approximation of the indigestible material in feedstuffs. Nevertheless, it is used as a general indicator in estimating the energy value of feeds. Feeds high in fiber will be low in ME.

Nitrogen-free extract (NFE) is determined by subtracting from 100 the sum of the percentages of ash, crude protein, crude fiber, ether extract and water. The NFE is considered to be a measure of the digestible carbohydrates. A criticism of the proximate analysis system, is that its major contributor, namely NFE, is calculated by difference, and not actually determined directly.

Proximate analysis gives some indication of the nutritive value of an ingredient. For example, a material very high in crude fiber is likely to have a low energy value, while feedstuffs low in crude fiber and high in ether extract are likely to be of high energy value. The crude protein content of material is a good indicator of its potential value as a protein source. Unless the amino acid composition is known, however, the actual quality of the protein cannot be determined. Certain ingredients such as meat meal normally contain a high quantity of ash. In meat meal and fish meal, calcium and phosphorus may be estimated from the ash value since it consists mainly of bone ash. Thus a determination of the ash of these materials may be very useful.

Proximate analyses should perhaps be better termed 'approximate analyses', especially since its main component, NFE, is determined by difference. However, it is a useful starting point for necessity to conduct other more specific analyses.

c. *Amino acid analyses*

Determination of total amino acids is time consuming and expensive and so tends not to be a routine procedure. The most common procedure today is gas-liquid chromatography, which can be highly automated to give relatively speedy analyses. However, the major time factor resides in preparation of the sample for analysis, since the component amino acids have to be freed from within protein structures. This pre-analysis procedure is usually termed hydrolysis, and unfortunately care must be taken during this process, since two important amino acids can be destroyed by inappropriate processing. Tryptophan is almost completely destroyed by acid hydrolysis and can only be determined following alkaline or enzymatic hydrolysis. The acid buffers used in amino acid analyses also cause loss of tryptophan. Special precautions also must be taken against loss of methionine and cystine during hydrolysis. Perfomic acid oxidation is usually carried out prior to hydrolysis, such that methionine is converted to methionine sulfone and cystine to cysteic acid. Amino acids are then liberated from the proteins by hydrolysis with HCl. In the case of tryptophan, further precautions against destruction by acids and alkalis are essential. Such problems in preparation of samples are often the reason that tryptophan is omitted from published data.

For measurement of digestible (available) amino acids, it is necessary to feed birds and measure total amino acids in the feed and excreta. The difference between amino acid input and output is assumed to be digestible or available amino acids. The bioassay is most easily achieved

by the TME precision force-feeding system, because the ingredient can be considered alone. In a classical bioassay, the bird voluntarily eats feed and only the test ingredient can supply amino acids. This situation means that semi-purified diets (containing other basal ingredients such as sugar, starch, sand and oils) are necessarily used and the practicality of such diets are often questioned. Today, virtually all estimates of amino acid digestion are derived from the force-feeding method, and values are often termed TAAA (True Amino Acid Availability).

d. Metabolizable Energy (AME or TME)

Metabolizable energy is the most costly nutrient in an ingredient or diet, yet unfortunately it is the most difficult to measure. As for digestible amino acids, estimates of AME or TME require a bioassay involving live animals. The only lab assay for energy is gross energy and this is merely a starting point used in AME or TME determinations. Gross energy is the total heat evolved when an ingredient or diet is burned in an atmosphere of oxygen. Wood and corn have approximately the same gross energy.

In an energy bioassay, birds are fed diets containing a given quantity of the ingredient, and feed intake and excreta output measured over a 3–5 d balance period. Gross energy is determined on feed and dried excreta and calculations made to determine the metabolizable energy derived from the ingredient under test. In the TME assay, the bird is force-fed only the ingredient under test, and so the estimate of ME is simplified. With all the laboratory and sample preparation necessary for the test, it is challenging to generate results within a 2–3 week period, at a cost approaching $1,000 USD per sample.

Because of the complexity and cost involved in measuring AME or TME, various chemical or *in vitro* systems have been developed. Essentially these methods attempt to correlate more easily measurable components, with available energy. One of the first such calculations was applied by Carpenter and Clegg (1956) and their equation is still as good as anything developed in the last 50 years.

ME (kcal/kg) = 53 + 38(%CP + 2.25 x % fat + 1.1 x % starch + % sugar)

This type of prediction equation is accurate to within ± 200 kcal/kg and so is useful for giving an estimate of AME for a novel ingredient. There have also been ME assays based on enzyme digestion. The most successful uses duodenal fluid taken from a pig, and measuring the gross energy of solubilized components after 1 – 2 hr of incubation. AME has also been predicted by NIRA (see next section).

e. Near Infra Red Analysis (NIRA)

NIRA offers the possibility for very rapid analyses of ingredients and feeds. The technique has the potential to assay many organic compounds. The system has the capability to measure metabolizable energy as well as more simple components such as fat, moisture, protein and fiber. Analysis relies on measuring how much light energy is absorbed when the sample is bombarded with light at very specific wavelengths.

The basis of NIRA is chemometrics, which is the application of mathematics to analytical chemistry. The technique is an integration of spectroscopy, statistics, and computer sciences. Mathematical models are constructed that relate chemical composition (active chemical groups) to energy changes in the near infra red region of the spectrum which ranges from 700 to 2500 nm in wavelength. In this region of the spectrum we

measure mainly vibrations of chemical bonds in which hydrogen is attached to atoms such as nitrogen, oxygen, or carbon. Because most feedstuffs are opaque, NIRA uses reflectance instead of transmittance. The reflected light of a sample is used to indirectly quantify the amount of energy absorbed in a sample. NIRA measures the absorption of infra red radiation by various components, for example, peptide bonds at specific wavelengths in the near infra red spectrum. Other components of the sample absorb energy as well, however, and have the effect of interfering. This effect is eliminated by mathematical treatment of the spectral data and by multiple linear regression or other statistical procedures.

Because each molecule usually exists in its lowest energy state, absorption of energy will raise its energy state to some degree. Such energy absorption occurs at a wavelength that is characteristic for that particular molecule. Energy absorption in the fundamental infra red region is very strong, but also very specific for certain molecular groups. For example, water has a characteristic absorption at the same wavelength as does starch. Strong, but specific fundamental wavelengths, would be difficult to differentiate for these two components. This does not mean to say that infra red analysis does not have a place in feed analysis. For example, with pure nutrients (amino acids, vitamins) the use of light reflectance in the fundamental range may offer potential for very specific analysis of purity. With samples of mixed composition, whether it be ingredients or complete feeds, then a more subtle analysis must be used to differentiate all the various chemical groupings. In the weaker absorbing NIR range of wavelengths, it is secondary absorption wavelengths that are considered – these are most often referred to as 'overtones'. By considering a spectrum of wavelengths, a characteristic pattern of absorption energy is given for each major component of the sample. Chemometrics then involves calculation of correlation coefficients at each wavelength and simultaneously selecting both the best fit with the nutrient under study, and also the best fit at all other absorption frequencies so as to remove all interference problems with application of a correction factor.

The usefulness of NIRA, therefore depends entirely on the careful and conscientious calibration of the equipment. To some extent this exercise has been simplified through introduction of so-called scanning machines that cover a wide band of NIR. Prior to this technology, only fixed wavelength equipment was available, and so prior knowledge of likely absorption bands or tedious testing of numerous wavelengths was essential in order to develop useful calibrations.

Developing calibrations for components such as moisture, fat, crude protein and fiber is a very straightforward procedure. These calibrations can be combined within a single program such that from each ingredient scan, these various analyses are conducted concurrently. For most commercial machines, ensuring consistent fineness of grind and controlling moisture content of samples eliminates much of the variation associated with operating procedure.

Determination of ME with NIRA provides a considerable challenge. Firstly, there is a need for an extensive range of diets of determined analysis to be used for calibration. The conventional bioassay for ME is both time consuming and very expensive, and these facts have undoubtedly limited investigation to date. Secondly, ME *per se* provides a complex problem for NIRA, because energy contribution is not confined to one nutrient but rather is represented by a range of molecular bondings and configurations. Usefulness of NIRA to predict ME therefore depends upon careful bioassay of a range of diets preselected in terms of anticipated ME, nutrient

contribution and ingredient composition. These latter parameters are of importance if 'universal' calibrations are to be developed. Similarly, great care must be taken in the mathematical manipulation of spectral coefficients. Over the last few years Valdes and Leeson (1992, 1994) have developed a number of such calibrations for feeds and ingredients. Table 2.17 shows some of these results for ingredients.

Table 2.17 Prediction of metabolizable energy by NIRA (kcal/kg)

Ingredient	*Determined*	*NIRA prediction*
Corn	*3380*	*3370*
Barley	*2720*	*2670*
Wheat	*3275*	*3225*
Soybean meal	*2340*	*2320*
Bakery meal	*2990*	*3005*
Tallow	*8690*	*8680*
Poultry fat	*9020*	*8840*
Corn oil	*9660*	*9530*
Palm oil	*7300*	*7700*

Adapted from Valdes and Leeson (1992, 1994)

There is also potential for NIRA to predict amino acids in ingredients (Table 2.18) as well as antinutrients such as glucosinolates or trypsin inhibitors. As with NIRA analyses, the accuracy of such predictions is greatly influenced by the time and precision involved in calibration using samples of known composition.

Table 2.18 Prediction of amino acids in fish meal

		%Amino Acid
	Assay	*NIRA prediction*
Methionine	*1.5*	*1.6 ± 0.06*
Cystine	*0.6*	*0.6 ± 0.07*
Lysine	*3.7*	*4.0 ± 0.30*
Tryptophan	*0.6*	*0.5 ± 0.03*
Threonine	*2.2*	*2.3 ± 0.09*
Arginine	*3.4*	*3.4 ± 0.09*

Valdes and Leeson (unpublished)

f. Urease testing of soybeans and soybean meal

Levels of the enzyme urease are used as an indicator of trypsin inhibitor activity. Urease is much easier to measure than is trypsin inhibitor and both molecules show similar characteristics of heat sensitivity. A rapid qualitative screening test for urease can be carried out using conversion of urea to ammonia in the presence of an indicator.

A qualitative test for urease activity can be carried out using a simple colorimetric assay. Urea-phenol-red solution is brought to an amber color by using either 0.1 N HCl or 0.1 N NaOH. About 25 g of soybean meal is then added to 50 ml of indicator in a petri dish. After 5 minutes, the sample is viewed for the presence of red particles. If there are no red particles showing, the mixture should stand another 30 minutes, and again if no red color is seen, it suggests overheating of the meal. If up to 25% of the surface is covered in red particles, it is an indication of acceptable urease activity, while 25 – 50% coverage suggest need for more detailed analysis. Over 50% incidence of red colored particles suggests an under-heated meal.

g. Protein solubility

Plant proteins are normally soluble in weak alkali solution. However, if these proteins are heat-treated, as normally occurs during processing of many ingredients, the solubility of protein will decline. Dale and co-workers at Georgia have developed a fairly rapid test which seems to give a reasonable estimate of protein solubility and hence protein quality in soybean meal. The assay involves adding just 1.5 g of soybean meal to 75 ml of 0.2% potassium hydrox-

ide solution, and stirring for 20 minutes. Soluble proteins will be in the liquid phase and so all or a portion of the centrifuged liquid is assayed for crude protein, and protein content relative to the original 1.5 g sample calculated accordingly. By knowing the crude protein content of the original sample of soybean meal, percentage solubility can easily be calculated. Typical results, as shown by Dale and Araba are given in Table 2.19. As heating time is increased, there is a decrease in protein solubility. Values of 75–80% solubility seem to be ideal, with higher values suggesting under-heating, and lower values over-heating of the protein. A variation of this test is to assess protein solubility in water. Sometimes termed Protein Solubility Index, the results of water solubility are said to be more highly correlated with feeding value than are estimates of urease index or protein solubility in KOH.

h. Protein and amino acid dye-binding

Proteins will bind with a number of dyes and so this provides the basis for colorimetric assays. These dye-binding techniques can be used to test protein *per se* or used to test for protein in various extractions involved in assays of solubility or digestibility. Dye-binding can therefore replace the Kjeldahl analysis depending upon sensitivity needs. The most commonly used methods are as follows:

Cresol Red	J. Amer. Assoc. Anal. Chem. 43:440
Orange G	J. Nutr. 79:239
Coomassie Blue	Anal. Biochem. 72:248

Lysine also reacts with certain dyes to give a colorimetric assay. Carpenter suggested that if the e-amino group of lysine is free to react with dye, then the lysine can be considered as 'available'. The most commonly used dye is Fluoro-2,4 dinitrobenzene (FDNB), which gives a yellow/orange color when combined with lysine.

Table 2.19 Protein solubility of samples of soybean meal heated for various times

Heating time	*Urease (ph change)*	*Protein solubility (%)*	*Wt gain (g)*	*Feed:Gain*
0 (Raw)	*2.40*	*99.2*	*343^{d}*	*2.44^{c}*
5 min	*2.04*	*87.7*	*429^{c}*	*2.29^{bc}*
10 min	*0.23*	*79.1*	*481^{ab}*	*2.00^{a}*
15 min	*0*	*74.9*	*496^{a}*	*2.09^{ab}*
20 min	*0*	*71.8*	*500^{a}*	*2.03^{a}*

Dale and Araba (1987)

i. Fish meal gizzard erosion factor

In some countries, fish meal is an economical feed ingredient to use in poultry diets. As previously described, some samples of fish meal will cause severe gizzard erosion in young birds. Where fish meal is an integral part of a broiler diet, then it is common to carry out a chick growth test with each shipment of fish meal. About 50 chicks are fed a broiler starter diet, usually without any fish meal, for 5 – 7 days. At this time, the diet is mixed with 40 – 50% of the test fish meal, and this diet fed for another 7 – 10 days. Birds are then sacrificed and the gizzard examined for erosion, often using a subjective scale as follows:

1. very mild erosion, with good gizzard color
2. mild erosion, with evidence of destruction of the lining in some areas
3. erosion in localized areas, with cracks in the thinner lining
4. severe erosion, cracking, thinning and discoloration
5. sloughing of the gizzard lining with hemorrhage

Because 40 –50% fish meal is used, some gizzard erosion is expected with most samples. Scores of 4 – 5 are often used to reject samples, although this decision will to some extent depend upon the level of fish meal to be used in the commercial diet.

j. Sorghum tannins

Tannins are detrimental to protein utilization, and so levels should be minimized in poultry diets. Sorghum is a potential source of tannin, and this is usually found in the outer seed coat. Unfortunately, there is not a clear relationship between seed coat color and tannin content. High tannin sorghums are usually darker in color, but some dark colored sorghums are also low in tannin. The tannins are present in the testa, which is the layer immediately beneath the outer pericarp. One quick test is therefore to cut into the seed and observe for presence of a pigmented (tannin) testa. More recently, a bleach test has been developed which again shows presence, or not, of a pigmented testa. About 20 g of sorghum is mixed with 5 g potassium hydroxide crystals and 75 ml of household bleach. The mixture is shaken until the KOH dissolves, and then set aside for 20 minutes. Sorghum grains are then strained, rinsed with water and placed on a paper towel. The KOH will remove the outer pericarp, and expose the testa. High tannin grains will appear dark brown/black while low tannin sorghum will be bleached white/yellow.

k. Gossypol in eggs

Feeding gossypol to laying hens can result in discoloration of both the yolk (green-brown) and albumen (pink). Gossypol is usually found in cottonseed meal and, as described previously for this ingredient, there are ways to minimize the effects of this compound by diet modification. However, egg discoloration occurs periodically, and cottonseed meal or cottonseed oil is often suspected. Placing egg yolks in a petri dish with ammonia quickly causes varying degrees of brown discoloration depending upon gossypol content.

l. Fat assays

Fat quality is best assessed by measurement of moisture, impurities and individual fatty acids. However, there are a number of less extensive tests that can be used to give some idea of fat composition and quality. Fat titre is a measure of hardness, and simply relates to melting point. The break-point between tallows and greases is about 40˚C. The higher the melting point, the more saturated the fat. Titre should obviously be consistent for an individual class of fat or fat blend from any one supplier. Iodine value can also be used as a measure of hardness. Each double bond (unsaturated) will take up a molecule of iodine, and so higher values mean a greater degree of unsaturation, which in turn should relate to lower titre (Table 2.20). Iodine value is greatly influenced by levels of palmitic, oleic and linoleic acid in most fats and oils. Generally, as titre increases by 10 units over the range of 50 – 100, then palmitic acid content decreases by about 2%. Also as a rule of thumb iodine value = 0.9 x % oleic acid + 1.8% x linoleic acid.

Table 2.20 Iodine value and titre of common fats

	Iodine Value	*Titre°C*
Tallow	45	45
Lard	65	40
Poultry fat	80	35
Vegetable oil	120	15

A major concern with the quality of fats and oils, is rancidity or the potential for rancidity. Rancidity is an irreversible oxidative process, that is autocatalylic, meaning that breakdown products fuel further degradation. Rancid fats will be less palatable, less digestible, and in extreme cases, the process of oxidative rancidity can continue in the body of the bird following consumption of these fats. The Initial Peroxide Value (IPV) is often used to measure degree of rancidity upon delivery of a fat. An IPV in excess of 18 – 20 meq is cause for concern. If a fat is not stabilized with an antioxidant, there is potential for subsequent rancidity during storage. This potential can be measured by creating extreme conditions for rancidity, namely bubbling pure oxygen through the heated sample for 24 hr, and re-measuring peroxide value. As a word of caution, peroxide build-up is time dependent, since after reaching a peak, there is a breakdown of peroxides to other indigestible compounds. Therefore fats that have finished oxidizing can show a low peroxide value, but have very poor nutritive value. Such samples are best detected by their 'rancid smell'.

m. Hulls in rice by-products

Rice bran, sometimes called rice pollard, is used extensively in rice growing areas of the world. The major variable affecting nutritive value, is the content of hulls, which are essentially indigestible for poultry. A major component of hulls is lignin, and this reacts with the reagent phloroglucinol to produce a color reaction. The reagent is produced by combining 1 g of phloroglucinol with 80 ml 2M HCl and 20 ml ethanol. The rice by-product is mixed 1:2 with reagent and held at about 25ºC for 10 minutes. Development of red color will be directly proportional to hull content. Actual hull content and a color scorecard are necessary to 'calibrate' the assay.

n. Mineral solubility

Neutralizing mineral salts with various acids can be used to give some idea of mineral availability, and when an assay is monitored over time then information on rate of solubility is also obtained. Hopefully, all mineral sources will be totally available to the bird, although, at least with calcium sources, there is concern about solubility. Slow solubilization is preferable to very rapid solubilization, because the former more closely matches the prolonged duration of need for calcium supply to the shell gland in laying hens.

Limestone solubility can easily be measured by monitoring pH of the mineral in dilute acid. After recording the original pH of a 90 ml aliquot of 0.1 N HCl, 10 g of limestone is gradually added, and without stirring, pH measured after time intervals of say 10, 20, 30 and 60 minutes. Limestone will result in an increase in pH, as H+ ions are liberated from solution. A pH change of +0.1 relates to a 20% solubility, while changes of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 relate to about 37, 50, 60, 70, 75, 80, 84, 87 and 90% solubility respectively. A pH change of +2.0 means 99% solubility. A high solubility after 60 minutes is expected from a quality limestone, whereas the rate of achieving 95 – 99% solubility will give an indication of the rate of calcium release in the proventriculus. Particle size and particle porosity are the factors most likely to affect rate of change of solubility. Optimum eggshell quality, and perhaps bone development in young birds, are dependent upon a consistent pattern of calcium solubility.

Neutralization of ammonium citrate has been used to assess solubility of phosphate sources and also of manganese and zinc salts.

2.3 FEED ADDITIVES

A number of additives are often used in poultry diets and most of these do not contribute any nutrients *per se*. Most additives are used to improve physical diet characteristics, feed acceptability or bird health. The following discussion is not intended to emphasize efficacy of the various products but rather to highlight various implications of their use in terms of diet formulation, ingredient compatibility and/or general feeding management.

a. Pellet binders

When pellet quality is of concern, a pellet durability index is often ascribed to ingredients and this is considered during formulation. This index may range from 55 – 60 for corn soy diets that are notoriously difficult to pellet, to 90 – 95 for wheat-based diets. With corn-based diets, it is often necessary to use synthetic pellet binders in order to achieve desirable pellet quality. In most instances, the need for a good pellet is necessary to placate the purchaser of the feed, because the bird *per se* is often tolerant of a range of quality in terms of growth rate and feed efficiency. The turkey poult is perhaps the most sensitive to pellet or crumble quality, where growth rate can be markedly influenced by both pellet size and the proportion of fines. The pelleting process is discussed in more detail in the following section on Feed Mixing and Pelleting.

A number of pellet binders are available, although they are used at considerably different inclusion levels, and such levels should be clearly specified for each product. When wheat or wheat by-products are used at less than 10% of the diet, then a binder will often be necessary if high pellet durability is desired. The two major types of binders have lignosulfonate or colloidal clays as the base product, with inclusion levels of around 5 – 12 kg/tonne. There have been reports of colloidal-clay type products binding some B-vitamins and pigments in the gut, and so making them unavailable to the bird. The colloidal-clay products may also aid in reducing apparent moisture content of the bird's excreta and more recently, some forms of clay have been shown to have activity in binding aflatoxin. The lignosulfonate pellet binders often contain 20 – 30% sugars, and so contribute to diet energy level. Studies show lignosulfonate binders to have ME values of 900 – 2200 kcal/kg depending upon sugar content. Because these binders are often used at 1 – 1.2% of the diet, then energy contribution is meaningful at 10 –25 kcal/kg of diet.

b. Anticoccidials

Anticoccidials are used in diets for most meat birds and young breeding stock that are reared on litter floors. Over the past 20 years, the so-called ionophore anticoccidials have predominated and they have proved most efficacious in controlling clinical signs of coccidiosis. From a nutritional viewpoint, some care must be taken in selection of these products as they can influence metabolism of the bird under certain situations.

Monensin has been a very successful anticoccidial, and seems to work well with both broiler chickens and turkeys. Monensin, like most ionophores, has an affinity to bind metal ions, the most important in terms of bird metabolism being sodium and potassium. Lasalocid also binds metals, although its major affinity is for potassium and secondly, sodium. Most ionophores also increase the permeability of membranes to H^+ ions, a factor that may be of significance in acid-base balance. For this

reason, there needs to be more work conducted on ionophores for heat-stressed birds. Ionophores have been shown to alter mineral availability, although this should not be of concern under commercial conditions where most minerals are present in excess of requirements. Studies show that the effect of ionophores on mineral metabolism is not always consistent for various minerals. For example, monensin may lead to increased tissue level of certain minerals, while lasalocid has the opposite effect, yet for another mineral these effects could be reversed.

Ionophores, and monensin in particular, seem to have an adverse effect when used in conjunction with low protein (methionine) diets. When low protein diets or feed restriction are employed for birds less than 21 d of age, alternatives to ionophores should be considered in an attempt to alleviate potential growth depression, loss of uniformity and poor feathering. However, with normal diet protein levels, the ionophores do not have a measurable effect on TSAA requirement. Ionophores and monensin in particular do impart some growth depression in young birds, although this seems to be completely overcome with compensatory growth during the withdrawal or finisher period. For monensin, a 5 – 7 d withdrawal is optimum for compensatory gain, assuming that no major coccidiosis challenge will occur during this time. With minimal challenge, a non-medicated withdrawal diet is recommended, while in situations of high challenge, an alternative anticoccidial may be necessary.

There has also been some controversy on the relationship between wet litter and certain ionophore products. Lasalocid in particular has been associated with wet litter, and as such, recommendations are often given for reducing diet sodium levels when this anticoccidial is used. Under such conditions adjustment of chloride levels is often ignored, and as a consequence performance is sub-optimal. The relationship between ionophores and water intake has not been fully resolved other than the fact that birds fed monensin do seem to produce drier manure.

Non-ionophore anticoccidials are not used extensively in chicken broiler production, although their use is often recommended in shuttle programs. Nicarbazin is an anticoccidial that seems to work well in such shuttle programs, although again there are some potential problems with this product. Nicarbazin seems to accentuate the undesirable effects of heat stress, and if inadvertently added to layer or breeder diets at normal anticoccidial levels, can cause loss in reproductive performance. Nicarbazin fed to brown egg birds turns their eggshells white within 48 hr although this is completely reversible when the product is withdrawn from the feed. Even low levels of nicarbazin can cause some loss in shell color, and mottling of egg yolks, and loss in fertility and hatchability of breeders.

Amprolium is used extensively in diets for growing breeder pullets, because unlike the ionophores, it allows some build-up of immunity. Amprolium induces a thiamin deficiency in the developing oocysts, and as such, has been queried with respect to thiamin status of the bird. In most instances thiamin deficiency will not occur in birds, although cases have been reported of combinations of amprolium and poorly processed fish meal that is high in thiaminase enzyme, leading to thiamin deficiency in young birds.

Coccidial vaccines are now commonly used in breeders, and their use will likely increase for broilers. There has been some discussion about diet manipulation so as to improve the immune

response. Oocysts start to cycle when birds are 10 d of age, and if the litter is exceptionally dry this important cycling is less effective. Under such extreme conditions, it may be advisable to temporarily increase diet or water sodium levels, so as to stimulate water intake.

c. Antibiotics, Growth Promoters

There has been a gradual reduction in the use of antibiotics *per se*, although growth promoting agents are still used extensively in most regions. The mode of action of growth promoting agents is comparable to that of antibiotics in terms of beneficial modification of gut microflora. In this context, the type of dietary ingredients used may influence the efficacy of these products because microbial activity is influenced by digesta composition. There has been insufficient work conducted in this area, e.g. the beneficial effect seen when antibiotics are used with ingredients such as rye. It is unlikely that growth promoters result in increased digestibility of feed, rather improvements in feed efficiency are a consequence of increased growth rate and hence reduced days to market. Over the past few years, there has been criticism about the use of antibiotics in poultry feeds, especially with respect to the potential for build-up of microorganisms resistant to a specific antibiotic, and subsequent transfer of this resistance to known pathogens. In this context, the use of antibiotics such as penicillin, that are also used in human-medicine, come under very close scrutiny.

It is very difficult to grow broilers without the use of growth promoters, since clostridial organisms often proliferate and clinical necrotic enteritis develops. While some countries have a ban on sub-therapeutic growth promoters in the feed, their use is escalating as water additives. Without the use of such 'antibiotics', there will undoubtedly be greater risk of bacterial overgrowth in the bird's digestive tract and especially when 'poorly' digested ingredients are used since these provide substrates for microbial fermentation in the lower gut. Such enhanced microbial growth can have various consequences for the bird. If the microbes are pathogens, then disease can occur. With proliferation of non-pathogens there can still be effective loss of nutrients to the bird and undoubtedly such conditions contribute to 'feed passage' where feed particles can be seen in the excreta. Using germ-free (gnotobiotic) birds, there is invariably a decrease in diet AMEn, since there is no 'digestion' by microbes.

There will undoubtedly be future interest in developing nutritional strategies aimed at reducing our reliance on sub-therapeutic antimicrobials. In general, such strategies revolve around limiting the nutrient supply to the intestinal microbes, altering the lumen environment so as to hinder microbial growth and/or priming or improving the bird's immune response (Table 2.21).

If diets are made more digestible, then theoretically, there should be fewer substrates available for microbial growth. The greatest success in this area will likely occur from developments in feed processing and greater application of exogenous feed enzymes. There seems great potential for modifying gut pH, either with use of feed or water source acids, or simply by stimulating gizzard activity. Many organic acids are bactericidal, and while some are corrosive, there are few limitations in adding them to diets in terms of stability of most other nutrients. While such acids may not have a dramatic effect on pH of the small intestine, products such as lactic acid are bactericidal over quite a range of pH.

Table 2.21 Nutritional strategies to reduce reliance on sub-therapeutic growth promoters

	Areas of study	*Examples*
1. Limit microbial growth by limiting their nutrient supply	*1. Use more digestible ingredients* *2. Feed processing* *3. Use of feed enzymes* *4. Reduce diet nitrogen*	*Corn vs small grains* *Pelleting, expansion etc.* *NSP, lipase?* *Increased use synthetic AA's*
2. Limit microbial growth by manipulating digesta pH	*1. Feed/water acids* *2. Stimulate gizzard activity*	*Phosphoric, propionic, lactic acids* *Feed whole grain or large feed particles.*
3. Improve immunity to infection	*1. Vaccines* *2. Prime the immune system*	*Coccidiosis* *Fatty acids, Vitamin E*
4. Interfering with sites of bacterial attachment	*1. sugars*	*Mannanoligosaccharides*

Laying hens and especially broiler chickens today have very rudimentary gizzards. With increased gizzard activity, there will be greater HCl production from the proventriculus and this is obviously bactericidal. Stimulating gizzard growth and activity may, therefore become more important, and contribute to health management of the birds There are often reports of higher digestibility of broiler feeds when particle size of feed is reduced. However, in most of these trials, the 'young' broilers likely have a rudimentary gizzard. For birds that have previously been fed larger size particles and/or more fiber, such that gizzard activity is increased, then there is greater digestibility of feed with a larger particle size. Gizzard function is generally a factor of fiber content of the feed, together with consideration of feed particle size.

As detailed in Table 2.21 another potential substitute for antibiotics is mannanoligosaccharides (MOS). Gram-negative bacteria have mannose specific fimbriae that are used for attachment to the gut wall. Mannan derivates from the cell wall of yeast offer the bacterial fimbriae an alternate binding site, and consequently are excreted along with the undigested mannanoligosaccarhride. Adding 1 – 3 kg of MOS per tonne feed, depending on bird age, will likely be part of future strategies for growing birds on 'antibiotic-free' diets.

The other issue involving use of antibiotics and growth promoters in poultry feeds is the potential for tissue or egg accumulation of these compounds. Adherence to regulated withdrawal periods eliminates these problems, as does scheduling of mixing non-medicated and medicated feeds in the mill. Most countries are now establishing GMP and HACCP programs at

feed mills to eliminate any potential for antibiotic residues in poultry products.

A number of ingredients are still referred to as having 'unidentified growth factors'. On this basis, ingredients such as alfalfa meal, distiller's solubles, bakery yeasts and animal proteins are often added at 1 – 2% of the diet. Any 'unexplained' response to these ingredients most often relates to their containing trace levels of vitamin or natural antibiotic residues.

d. Antifungal agents

In many regions of the world, molds and associated mycotoxins are major problems, affecting both growth and reproductive performance. Mycotoxins produced by both aerobic field molds and anaerobic storage molds can accumulate, often undetected, in a range of ingredients. A number of antifungal agents are available, most of which are based on organic acids. By altering the pH of the feed, it is hoped to control mold growth, although it must be remembered that any mycotoxin already present in feed will not be destroyed by these antifungal agents. Apart from their cost, these organic acids can be problematic in accelerating the corrosion of metal feeders and mill equipment.

Gentian violet is also used in many countries as an antifungal agent, and in this context, its efficacy is governed by factors that determine the efficacy of organic acids (i.e.: time, temperature, moisture and feed particle size). Gentian violet also has some bacteriostatic activity and as such, is often used to maintain a beneficial gut microflora, comparable to an antibiotic. In recent years, there has been some interest in use of aluminosiliacate (zeolites) as an 'adsorbent' of aflatoxin, and also products based on yeast cell walls. Unfortunately, relatively high levels of aluminosilicates must be used and these provide no other nutrients and may, in fact, act as chelating agents for some essential minerals. However, where aflatoxin contamination is common, then adding up to 15 kg aluminosilicates per tonne of feed may be necessary in order to minimize the effect of this mycotoxin.

In addition to, or as an alternative to using such antifungal agents, there is a potential for minimizing mold growth through formulation, diet preparation and feeding management. There seems little doubt that the feed surface area is directly related to potential fungal activity since the greater the surface area of feed exposed to the atmosphere, the greater the possibility of fungal spore colonization. This fact is the most likely cause for the increase in mold growth often seen with feed as it travels from the mill to the feed trough because particle size is invariably reduced. Up to a 50% increase in fines can occur with high-fat pelleted broiler diets between the time of pelleting and consumption by the bird. At the same time, there is a 100% increase in the potential (and most often the occurrence) of fungal activity. In areas of potential mycotoxin contamination, there is obviously an advantage to maintaining as large a pellet or crumble size as possible. The heat generated during pelleting has been shown to sterilize feed to some extent, because fresh pellets have low fungal counts. However, pelleting will not destroy mycotoxins already formed prior to pelleting, and warm moist pellets are an ideal medium for fungal growth. Research has shown increased fungal activity in feed taken from trough vs tube feeders with the former having more feed exposed to the atmosphere.

With toxins such as aflatoxin, there is a benefit to increasing the protein content of the diet, and in particular, sulfur amino acids. It is possible that sulphates may also be beneficial in

helping to spare sulfur amino acids that are catabolized during aflatoxicosis. Due to the specific enzyme system involved with aflatoxicosis, selenium at up to 0.4 ppm may be beneficial in overcoming major adverse effects of this mycotoxin. There have also been reports of niacin increasing the catabolism of aflatoxin B1, and so decreasing overall toxicity.

It appears that diet modification and feed management can be manipulated to minimize chances of mycotoxicosis. However, such measures will not likely be 100% effective, and it should always be remembered that most fungal growth can be reduced if moisture content of grains and feeds is kept below 14 – 15%.

e. Probiotics and Prebiotics

Probiotics, unlike antibiotics, imply the use of live microorganisms rather than specific products of their metabolism. Not being specific molecules therefore, they are difficult to quantitate and even more difficult to describe in terms of proposed modes of action. Probiotics can be classified into two major types – viable microbial cultures and microbial fermentation products. Most research has centered on *Lactobacilli* species, *Bacillus subtilis* and some *Streptococcus* species. Similar to the situation with antibiotics, the mode of action is still unclear although the following have been suggested: a) beneficial change in gut flora with reduction in population of *E. Coli*; b) lactate production with subsequent change in intestinal pH; c) production of antibiotic-like substances; d) reduction of toxin release (suppression of *E. coli*). With these varied potential routes of activity, it is perhaps not too surprising that research results are inconsistent. In most instances, the feeding of live cultures modifies the gut microflora of birds usually with increases in number of *Lactobacilli* at the expense of coliforms. A healthy animal has a preponderance of lactic acid producing bacteria, and so it is only under situations of 'stress', when coliforms often increase in numbers, that probiotics will be of measurable benefit. In this context there is interest in the use of live cultures administered (orally) to day-old poultry as a means of preventing harmful bacteria such as salmonella from colonizing the gut.

The term 'competitive exclusion' is often used synonymously with probiotics. It is assumed that the probiotic will have a competitive advantage over any inherent pathogen, and either replace it, or prevent its colonization. Bacterial antagonism may arise due to synthesis of inhibitors by the probiotic organism. Lactic acid from *Lactobacilli* and other species is an example of such a product. Probiotic organisms may also stimulate mucosal immunity. While undefined mixtures of bacteria, usually derived from cecal contents of healthy adult birds, seem to be effective probiotics, regulatory agencies are often concerned about dosing animals with unknown organisms. Defined synthetic mixtures of bacteria seem less efficacious at this time, possibly because we have only scant knowledge of the normal (beneficial) microbial population within a healthy bird. However, this approach to developing a probiotic probably has the best long-term chance of success. With potential instability in most feeds for many *Lactobacillus* species, there has been recent interest in probiotics based on *Bacillus subtilis* species, because they possess a viable spore that has greater stability than do most lactic acid producing cultures.

Regardless of somewhat inconclusive results, it appears that probiotic use is increasing, and that the animal industry looks to such products as the substitutes for conventional antibiotics. These

products seem ideal candidates for genetic manipulation which has been inferred by a number of researchers in this area. By using genetic engineering, some researchers suggest that bacteria can be reformed to carry more desirable gene characteristics, including the production of digestive enzymes and antimicrobial substances.

Prebiotics are aimed at supplying probiotics with an advantageous source of nutrients, implying that their needs are different to those of the host and/or different to those of potential pathogens. Certain oligosaccharides, which resist endogenous enzyme degradation, seem to promote a more favorable microflora in the lower small intestine and also the large intestine. However, certain pathogenic bacteria, such as *Clostridium perfringens* are also able to ferment some of the oligosaccharides. There is some preliminary work with pigs suggesting synergism for certain combinations of prebiotics and probiotics, which is expected if both are efficacious.

f. Yeasts

Yeast, or single-celled fungi, have been used in animal feed and the human food industry for many years. Brewer's yeast was a common feed ingredient in diets for monogastric animals prior to the identification of all the B-vitamins. Today, some nutritionists still incorporate these inactivated microbes as a source of so-called 'unidentified growth factor'. More recently there has been an interest in the use of live yeast cultures. These cultures most often contain the yeast themselves and the medium upon which they have been grown. Yeast cultures are usually derived from *Saccharomyces* species, in particular, *Saccharomyces cerevisiae*. As with probiotics, their mode of action in enhancing animal performance is not fully understood. Yeasts may beneficially alter the inherent gut microflora, possibly through controlling pH. The presence of living yeast cells may also act as a reservoir for free oxygen, which could enhance growth of other anaerobes. At the present time, there does not seem to be any move to manipulate yeast for specific purposes related to animal nutrition. To some extent, this relates to scant knowledge on mode of action, and so should more facts be uncovered in this area so-called 'designer' yeast may be considered.

g. Enzymes

Enzymes have been added to poultry diets ever since workers at Washington State University showed improvement in digestibility of barley and rye-based diets when various enzymes were used. In the 1950's, corn-soybean diets predominated, and these were assumed to be highly digestible and so there was little interest in feed enzyme application. Over the past few years, this area of nutrition has gained interest and activity due to economics of small grain use and also because of a better understanding of mode of action and availability of various enzymes. Enzymes are now being manufactured specifically for feed use, and can be broadly categorized as carbohydrases, proteinases and lipases. Increasing the digestibility of various carbohydrate fractions of cereals and plant proteins has received most attention, although there is growing interest in the potential for improving digestibility of both plant and animal proteins, and of saturated fatty acids for young birds. Currently, enzymes are used most commonly to aid digestion of diets containing wheat, barley and rye where improvements are seen in dry matter digestibility and also in consistency of the excreta. There is also current interest in enzymes designed specifically to improve soybean meal digestibility.

The term non-starch polysaccharides (NSP) is now frequently used to describe what in the past has been referred to as fiber. Birds have a very limited ability to digest fiber because they lack the enzymes necessary to cleave these large and complex molecules. In animals such as the pig, and in ruminants, it is the resident microbial populations that synthesize cellulase type enzymes that allow for varying degrees of fiber digestion. If we can improve digestion of the complex carbohydrates, we not only increase potential energy utilization, but also remove any negative impact that these products may have on gut lumen activity and excreta consistency.

The NSP content of cereals and other by-product feeds is usually inversely proportional to their conventional energy level. These NSP components are most often associated with the hull and underlying aleurone layers. In order for normal endogenous enzymes to contact the starch endosperm, these outer layers must be disrupted or chemically degraded. Although many compounds fit into the category of NSP's, there are three main types of importance in poultry nutrition. These are the ß-glucans in barley, the arabinoxylans or pentosans in wheat and the raffinose group of oligosaccharides in soybeans. Barley ß-glucans are polymers of glucose while arabinoxylans contain long chains, and cross chains of fructose. The oligosaccharides in soybean are polymers of sucrose. Most cell wall NSP's either exist alone or as structural material often complexed with protein and lignin. Solubility of NSP's usually relates to the degree of binding to lignin and other insoluble carbohydrates. In water, most NSP's produce a very viscous solution, and this has a predictably negative effect on digesta flow and interaction of all substrates with their endogenous enzyme systems. Some NSP's such as pectins, have a three-dimensional structure that can chelate certain metal ions. Any increase in digesta viscosity causes an increase in thickness of the unstirred water layer adjacent to the mucosal villi. Consequently, there is reduced solubilization and uptake of most nutrients. Digesta retention time increases, but because of the increased viscosity there is less opportunity for substrates to contact enzymes. There are also more endogenous secretions and these contain proportionally more bile acids. In addition to reduced digestibility, there are also reports of reduced net energy of diets due to NSP's. The reduced NE may be a consequence of increased energy expended by the digestive system in simply moving digesta through the system. The increased digesta viscosity also influences the gut microflora and there is an indication that their overgrowth may, in fact, add to the overall deleterious effects. To the poultry producer, the most notable effect of NSP's will be wetter, more sticky and viscous excreta. Table 2.22 details

Table 2.22 Non-starch polysaccharides in selected ingredients (%)

Ingredient	*Cellulose*	*Arabinoxylan*	*Pectin*	*ß-glucans*
Corn	*2.5*	*5.0*	*0.1*	-
Wheat	*2.5*	*6.0*	*0.1*	*1.0*
Barley	*4.8*	*7.0*	*0.2*	*4.0 – 5.0*
Soybean meal	*5.0*[1]	*0.5*	*12.0*	-

[1] *depending on hull fraction returned*

levels of NSP's commonly found in cereals and soybean meal. Oligosaccharides as found in soybean meal are perhaps the most complex structures within the NSP's and to date have proven difficult to digest with exogenous enzymes. Depending upon variety, growing conditions and oil extraction procedures, soybeans will contain 4 – 7% of oligosaccharides mainly as raffinose and stachyose. Because of the absence of α-galactosidase in chickens, these oligosaccharides remain undigested, and again contribute to increased digesta viscosity, especially in young birds. Soybean oligosaccharides can be extracted using ethanol. Such treatment of soybeans is not commercially viable at this time, although the residual meal has an AMEn value approaching 3,000 kcal/kg, and the meal seems an interesting ingredient for very young birds. Since the oligosaccharides are removed by ethanol, then there is a corresponding loss of dry matter in the residual soybean meal.

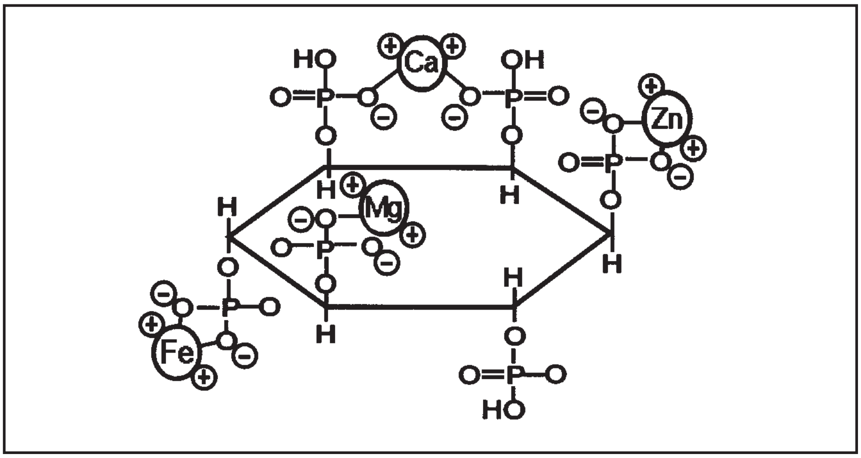
Addition of feed enzymes could therefore improve NSP availability, and just as important, reduce the negative impact that these undigested residues have on digesta viscosity. Normal digestion requires unimpeded movement of enzyme, substrate and digestion products throughout the digesta and especially close to the absorptive gut wall. As the viscosity of the digesta increases, the rate of diffusion decreases, and this causes reduced digestibility of all substrates. The undigested viscous digesta subsequently translates to very sticky excreta which causes problems of litter management. Reduction in digesta viscosity is therefore highly correlated with efficacy of enzymes that can digest substrates such as ß-glucans. In oats and barley the bulk of the NSP's are ß-glucans, whereas in wheat and rye, arabinoxylans predominate. Enzymes tailored for barley therefore contain ß-glucanase enzymes, while those designed to improve wheat digestibility should contain cellulase and arabinoxylanase enzymes.

There is potential for adding lipase enzymes to feeds or fats, to improve digestibility. Improvement in digestion of saturated fats for young birds seems to have the greatest potential. Although there are no lipase enzymes currently designed for use in animal feeds, preliminary studies with enzymes obtained from other industries suggest that a 7 – 10% improvement is possible, with a corresponding increase in diet AME. Since the young chick does not efficiently re-cycle its bile salts, there have also been indications that fat digestion can be improved by adding synthetic bile salts to the feed. Again, these are not commercially available, but it does suggest some potential for the development of emulsifying agents or detergents.

The most widely used feed enzyme is phytase. Phytase cleaves the phytic acid in soybean meal and cereals, to release phosphorus and calcium. Phytic acid is a complex structure that tightly binds phosphorus, and is the main storage source of phosphorus in plant material (Fig. 2.1). Few animals possess the phytase enzyme necessary to cleave the molecule and so phytic acid is largely undigested. Interest in the phytase enzyme arose because phosphorus has become an expensive nutrient, as well as the fact that undigested phytic acid adds greatly to manure loading of phosphorus. Phytate also binds other trace minerals and may conjugate with proteins and carbohydrates. Digestion of the molecule therefore can potentially release trace minerals, amino acids and energy, as well as calcium and phosphorus.

Phytase enzymes are commonly found in plant materials, and especially for wheat and wheat

Figure 2.1 Phytic acid



by-products the values are quite high. Corn, for example, contains just 15 FTU/kg while wheat shorts can contain as much as 10,000 FTU/kg. However, such endogenous phytase may have only limited usefulness in the digestive tract, since most plant phytases are effective only at around pH 5, whereas exogenous phytases, usually of microbial origin, seem efficacious from pH 3 to 7. There are variable results reported for efficacy of phytase in commercial diets. It has been suggested that diet calcium level is perhaps the major factor in such variance, since high levels of calcium seem to reduce the effectiveness of phytase enzyme. However, if this concept is true, then one wonders why phytase enzymes seem so efficacious in layer diets that contain from 4 – 4.5% calcium. If phytase is used in formulation, there are a number of different approaches to account for increased phytate availability. Where few ingredients are used, the available phosphorus level of these ingredients can be increased accordingly. Alternatively, the specification for available phosphorus in the diet can be reduced or phytase enzyme can be included as an ingredient with specifications for available phosphorus and calcium. Each 500 units of phytase activity are equivalent to about 1 g of phosphorus as provided by sources such as di-calcium phosphate. Using 500 FTU of phytase/kg feed therefore provides the equivalent of 0.1% P.

Phytase also liberates some trace minerals and so theoretically, supplemental levels can be reduced. As described previously for calcium, there is an indication that phytase is more effective when moderate, rather than high, levels of supplemental zinc are used. The release of energy and amino acids by phytase is a more contentious issue. Some research suggests up to 2% improvement in AMEn and digestible amino acids, although more conservative estimates are for 15 kcal ME/kg release of energy, with no increase in amino acid availability. Some commercial sources of phytase are sensitive to heat, and pelleting at 85 – 90ºC can cause significant loss in phytase. In pelleted feeds, these sources of phytase are most appropriately used as post-pelleting additives. Other sources of phytase seem more heat stable, and can be added to the mix prior to pelleting.

h. Pigments

The yellow to orange color in avian fatty tissue is caused by various carotenoid pigments. These pigments control the color of the egg yolk, as well as the shanks and beaks of layers, and also the skin color that may be important in meat birds. The xanthophylls are the most important carotenoids in poultry nutrition, and natural ingredients rich in these compounds are alfalfa meal, corn gluten meal and marigold petal (Table 2.23).

Table 2.23 Xanthophyll content of selected ingredients (mg/kg)

Ingredient	*Xanthophyll*
Corn	*20*
Wheat	*4*
Milo	*1*
Alfalfa meal	*175*
Corn gluten meal	*275*
Marigold petal	*7,000*

Corn contains much more xanthophylls than do other cereals, although high levels of pigmentation can only be achieved from natural ingredients by including other products such as alfalfa and corn gluten meal.

The various xanthophylls differ in their effect on skin and yolk pigmentation. ß-carotene has little pigmenting value, although pigments such as zeaxanthin as found in corn, is more easily deposited, while there is a very high incorporation rate of synthetic products such as ß-apo-8-carotenoic ethyl ester. The zeaxanthin in corn tends to impart the darker orange-red colors, whereas the luteins, as found in alfalfa, cause a more yellow color. Pigments are destroyed by oxidation, and so addition of antioxidants to feed, and general feed management applied to fat protection also apply to preservation of pigments. Coccidiosis, malabsorption and certain mycotoxins will all reduce pigment absorption. Pigmentation in the young meat bird is directly proportional to pigments fed throughout growth. For the laying hen however, yolk color is a consequence of pigments consumed in the layer feed, and also the transfer of pigments accumulated in the skin and shanks when the bird was immature. This transfer of pigments to the ovary occurs regardless of diet pigments, and is responsible for the 'bleaching' effect of the shanks and beak of yellow-skinned birds over time.

Because many of the naturally carotenoid-rich ingredients are low in energy, it is difficult to achieve high levels of pigmentation of meat birds without using various synthetic sources. Canthaxanthin, astaxanthin and ß-apo-8-carotenoic acid (where allowable in poultry diets) can be used to impart the spectrum from yellow to orange/red coloration in either skin or egg yolk. As described more fully in Chapter 4, there is now interest in enriching eggs with lutein, since this carotenoid is known to be important in maintenance of eye health in humans. Future designer eggs may well contain concentrated levels of lutein.

i. Flavoring agents

The chicken is not usually considered to have the ability to select feed based on flavor, or organoleptics *per se*. The chicken has only about 24 taste buds in comparison to 9,000 in humans and 25,000 in cattle. Relatively few studies have been conducted with flavoring agents for poultry, and for this reason, care must be taken in extrapolating data from other species. For example, sucrose octa-acetate solution is reported to be readily accepted by birds, but universally rejected by humans. There seems little scope for use of flavoring agents with broiler chickens and turkeys that already seem

to be eating at near physical capacity. However, there may be some potential with breeders for identification of agents that are distasteful to birds, as an aid in limiting their feed intake.

We have studied the effect of feeding cinnamamide to young broilers, as a means of regulating feed intake. Cinnamamide is related to the spice known as cinnamon and is a naturally occurring product in some weed seeds that is thought to impart bird resistance characteristics as do tannins. Table 2.24 shows the effect of feeding cinnamamide on growth and feed intake of young broilers. At the highest inclusion level, cinnamamide reduced voluntary feed intake by around 50%.

Table 2.24 Effect of cinnamamide on feed intake and body weight of young broilers

	Body Weight (gms)		*Feed Intake 4-12 day (gms/bird)*
	Day 4	*Day 12*	
Control	*82.2*	*266.4*	*257.3*
Cinnamamide (0.2%)	*81.4*	*170.8*	*159.2*
Cinnamamide (0.42%)	*82.8*	*122.7*	*104.4*

Flavor agents may be beneficial in masking any unpalatable ingredients, and for maintaining a constant feed flavor during formulation changes. Flavors may also be useful tools in masking any undesirable changes in drinking water during medication. It is conceivable that use of a single flavor agent in both feed and medicated water may prevent some of the refusals seen with medicated water, especially for turkey poults.

j. Worming compounds

Most floor grown birds are exposed to infection from various species of worms. In many instances such challenge can be prevented or minimized with the use of antihelmintic agents. Products based on piperazine and hygromycin have been used most commonly over the last 15 – 20 years. Piperazine used in diets for laying birds has been shown to result in discoloration of the yolk. When administered at 28 d intervals, one report indicated about 4% incidence of discolored yolks which appeared as irregular areas of olive to brownish discoloration. Such yolk discoloration is most pronounced in summer months especially after prolonged storage at regular egg cooler temperatures. The mottling of yolks seen with another commercial product has been compared to the mottling seen with calcium-deficient birds, suggesting a similar mode of action. However, we are unaware of any published reports relating worming compounds to calcium deficiency and problems with shell quality.

k. Ammonia control

Various extracts of the yucca plant are claimed to reduce ammonia levels in poultry houses. A soluble component of the yucca plant seems able to bind ammonia, preventing its release from manure, which is especially important in confinement housing systems. Most poultry will react adversely to 50 ppm ammonia, and this is in contrast to the level of 20 – 30 ppm which is the usual detection range for humans. Products such as Deodorase® added to feed at 100 – 150 g/tonne have been shown to reduce environmental ammonia levels by 20 – 30%, and this has been associated with improved growth rate and reduced mortality.

2.4 FEED TOXINS and CONTAMINANTS

Producing poultry feed that is free of toxins and contaminants is obviously the goal of all feed mills. However, this is difficult to achieve because many natural feed ingredients will contain toxins that are inherent in the feedstuff or have 'naturally' contaminated the feedstuff prior to feed preparation. Mycotoxins are perhaps the best example of such 'natural' toxins, and together with many plant lectins can cause poor bird growth and reduced egg production. In addition to these biological contaminants, there is also concern about accidental inclusion of such products as polychlorinated biphenyls, pesticides, fungicides etc.

a. Mycotoxins

Mycotoxins are now virtually ubiquitous in poultry diets, and with ever increasing sophistication of testing sensitivity, they are routinely isolated as contaminants of most grains and some vegetable protein ingredients. We still do not know the cause of high levels of mold growth occurring in pre-harvest grains. Certainly such aerobic molds are more prevalent in hot humid conditions, and insect damage to the standing crop seems to provide a route of entry for the mold. Unfortunately, visual inspection of harvested grains can be misleading in regard to mycotoxin content. Likewise, merely because grains appear moldy, does not mean to say that they are contaminated with harmful toxins. In storage, the major factors affecting mold growth are again temperature and humidity. The higher the temperature, the greater the chance of mold growth. However such mold growth rarely occurs in grains containing less than 14 – 15% moisture. Unfortunately, many grain silos are not waterproof, or grains are not aerated, and so pockets of moisture can cause microclimates ideal for mold growth. The following is a review of the major mycotoxins affecting meat birds and egg layers.

Aflatoxin - Produced by the *Aspergillus flavus* mold, aflatoxin is one of the most potent carcinogens known. Usually present in cereals in ppb levels, acute toxicity will occur at 1.2 ppm. Aflatoxin B_1 is the most common form of the toxin, the B designation relating to the fact that the toxin fluoresces a blue color when exposed to ultraviolet light, and so this can be used in the screening of ingredients. Blue fluorescence occurs with other components, and so this simple test screens out negative samples, but needs subsequent chemical analysis for confirmation. Aflatoxin is found in most cereals, although corn and milo are the most common hosts. As with any mold, *Aspergillus* growth is greatly reduced when corn or milo moisture levels are less than 15%.

Aflatoxin is a potent hepatotoxin, and so varying degrees of liver breakdown occur. As toxicity develops, normal liver function declines, and reduced growth rate is quickly followed by death. Toxicity is enhanced by the presence of other toxins such as ochratoxin and T2 toxin. The effects of aflatoxin are also much worse if birds are infected with aspergillosis. There also seems to be a nutrient interaction, because toxicity is more severe when diets are low in either crude protein or methionine or when the diet contains marginal levels of riboflavin, folic acid or vitamin D_3. There is no treatment for acute aflatoxicosis, although because of the liver disruption, giving higher levels of antioxidants and/or selenium seems to slow the onset of symptoms and speed up recovery if aflatoxin is removed from the diet.

There are a number of effective preventative measures, although not all of these are economical. Treating infected grains with ammonia, hexane or hydrogen peroxide have all been shown to reduce aflatoxin levels. Under commercial conditions adding binding agents to the feed seems to reduce the adverse effects of aflatoxin. To date, aluminosilicates, bentonite clays and yeast cell walls have proven effective. For example adding 10 – 15 kg/tonne of hydrated sodium-calcium aluminosilicate has been shown to drastically reduce mortality in broilers and turkeys fed diets containing 0.5 – 1.0 ppm aflatoxin. Such aluminosilicates have limited effects on other mycotoxins.

Tricothecenes - Three mycotoxins, namely T_2, DAS (diacetoxyscirpenol) and DON (Deoxynivalenol or vomitoxin) are included in this group. All of these mycotoxins are produced by *Fusarium* species molds such as *Fusarium graminearum* and *Fusarium roseum*. The tricothecenes affect protein metabolism and have the characteristic feature of causing mouth lesions in most animals. However DON does not seem to be particularly harmful to poultry. Unlike the situation in pigs and other mammals, birds can tolerate up to 20 ppm of this mycotoxin. T_2 and DAS however are more toxic, causing problems at 2 – 4 ppm. The adverse effect of tricothecenes is made even worse by the presence of aflatoxin or ochratoxin, and seems to be worse in young broilers fed ionophore vs non-ionophore anticoccidials. There are no really effective treatments, and while the addition of relatively high levels of antioxidants may slow the disruption of protein synthesis, they are not effective long-term. Adsorbents and binding agents are being developed that specifically bind these toxins.

Ochratoxin - As with other mycotoxins, there are a number of forms of ochratoxin, although ochratoxin A (OA) is by far the most significant for poultry. OA is produced by a number of molds, with *Aspergillus* and *Penicillium* species being most commonly involved. OA is toxic at 2 ppm and as with tricothecenes, it has an adverse effect on protein synthesis. However, OA also affects kidney function and so the classical signs are swollen kidneys and associated increased water intake with wet excreta. Secondary visceral gout, which appears as urate deposits over the viscera, is common with OA toxicity, due essentially to failure of uric acid clearance by the kidney tubules. OA toxicity is compounded by the presence of aflatoxin, DON and T_2 toxicosis, and also made worse by feeding diets high in vanadium (usually as a contaminant of phosphates or limestone). There are no effective preventative measures, although birds sometimes respond to diet manipulation in the form of increasing crude protein levels. There are also reports of beneficial response to increasing diet vitamin C levels, especially in egg layers.

Other mycotoxins - There are a diverse group of other mycotoxins that periodically cause problems for poultry. Their occurrence is less frequent than the major mycotoxins already discussed, and in some instances exact toxicity levels have not been clearly established.Table 2.25 summarizes these mycotoxins in terms of effect on poultry and their probable threshold for toxicity.

b. Plant toxins

A number of cereals and vegetable protein crops contain natural toxins that can affect bird performance.

Cyanides - While there are a number of potential feed ingredients that contain natural cyanides, cassava (manioc), is probably the most common and contains relatively high levels of this toxin.

Table 2.25 Effect of minor mycotoxins on poultry

Mycotoxin	Effect	Toxicity	Comments
Fumonisin	*Degeneration of nerve cell lipids*	*> 80 ppm*	*Diet thiamin levels important*
Cyclopiazonic acid	*Mucosal inflammation*	*50 – 100 ppm*	*Often present along with aflatoxin*
Oosporin	*Kidney damage, gout*	*> 200 ppm*	*Most commonly found in corn*
Citrinin	*Kidney damage*	*> 150 ppm*	*Commonly associated with ochratoxin*
Ergot	*Tissue necrosis*	*> 0.5%*	*Wheat and rye*
Fusarochromanone	*Tibial dyschondroplasia*	*> 50 ppm*	*Fusarium species*
Moniliformin	*Acute death*	*> 20 ppm*	*Mechanism unknown*
Zearalenone	*Reproduction, vitamin D_3 metabolism*	*> 200 ppm*	*Can affect shell quality*

Cassava meal is derived from the tuberous root of the cassava plant. Ingestion of this material by animals can result in enlarged thyroids, due to the presence in the meal of cyanogenic glucosides, the main one being linamarin. These glucosides are concentrated in the peel of the root. On hydrolysis by the enzyme linamarase, the glucosides produce hydrocyanic acid (HCN), which is highly toxic. In addition to the enzyme in the root, glucosidic intestinal enzymes and HCl can also hydrolyze the glucosides.

Hydrocyanic acid inhibits animal tissue respiration by blocking the enzyme cytochrome-oxidase. HCN is detoxified to produce thiocyanate in the liver which is then excreted via the urine. This detoxification system utilizes sulfur from methionine in the conversion of cyanate to thiocyanate, thus increasing the bird's requirement for this amino acid. Thiocyanate is responsible for the goitrogenic effect of cassava, due to its effect on iodine uptake and metabolism in the thyroid, resulting in reduced output of thyroxine, which regulates tissue oxidative functions. Cyanate is known to alleviate the toxicity of an excess of dietary selenium by complexing with selenium, thus making it less available to the bird. Linseed meal, which has been known for some time to alleviate selenium toxicity in animals, has been shown to contain two cyanogenic glucosides, namely linustatin and neolinustatin. These compounds are closely related in structure to linamarin and thus on hydrolysis yield HCN.

The cyanide content of cassava varies with variety and can range from 75 to 1000 mg/kg of root. Crushing the root releases the enzyme linamarase which acts on the glucosides to

produce volatile HCN which is then eliminated during drying. Rate of drying in commercial forced air driers is important as it has been reported that at 80 to 100ºC, only 10 to 15% of cyanide is removed compared to 80 to 100% detoxification occurring at 47 to 60ºC but with a longer time. Steam pelleting can also assist in the volatization of free HCN.

While there are differing reports as to how much cassava meal can be incorporated into poultry diets without reducing performance, this will obviously depend on the concentration of cyanide in the meal. Cassava meals containing up to 50 mg total cyanide/kg have been fed successfully up to 50% inclusion in broiler diets.

Glucosinolates – These belong to a group of anti-nutritive compounds of which over 100 different types are known to occur in members of the Cruciferae family. The genus *Brassica* is a member of this family which includes many important feeds and foods such as, rapeseed, mustard, kale, radish, cabbage, cauliflower, etc. In individual species, usually around 12 to 20 glucosinolates are found, although most of these are present in small amounts. Hydrolysis of these glucosinolates is brought about by the enzyme myrosinase, which is usually present in most glucogenic plants. In the intact plant, the enzyme and its substrate are separated, but with cellular rupture (grinding, insect damage, etc.) these components are combined and hydrolysis can occur.

For many plants including rapeseed, glucosinolates can be readily divided into three main groups, based on physiological effects and hydrolysis products. By far the largest of these groups are glucosinolates that yield isothiocyanates on hydrolysis. These compounds are volatile and possess a range of antimicrobial, antifungal and antibacterial properties, and have a very pungent taste (mustard, horseradish, etc.). A second, but much smaller group, form potent anti-thyroid compounds on hydrolysis with 5-vinyloxazolidine-2-thione being the most common. If present in large amounts these compounds can impart an intense bitterness. Glucosinolates in the third group all contain an indole side chain, and on hydrolysis yield thiocyanate ions which are anti-thyroid or goitrogenic. The glucosinolate contents of the various rapeseed cultivars ranges from a high of 100 to 200 μM/g to less than 30 μM/g, while new varieties are claimed to be glucosinolate-free.

A significant research program was initiated in Canada in the early 60's to develop rapeseed varieties low in glucosinolates and erucic acid, a fatty acid known to result in detrimental metabolic problems with certain animals. In 1968, the first low erucic acid variety was licensed and shortly thereafter a low glucosinolate variety appeared. In 1974, the first double low variety, very low in erucic acid and glucosinolates was licensed. A number of improved varieties were developed and in 1979 the name canola was adopted in Canada to apply to all double low rapeseed cultivars. For reasons not yet completely understood, reduction of total glucosinolate had little effect on the content of the indole group. Thus, when expressed as a percent of total glucosinolates, this group increases from around 5 to 40% in the low glucosinolate varieties.

While the feeding value of canola meal has been markedly increased for poultry, as compared to the older rapeseed varieties, there are still some problems encountered. The occurrence of liver hemorrhages with the feeding of rapeseed meal is well documented. Unlike the fatty liver hemorrhagic syndrome, these hemorrhages are not associated with increased liver or abdominal fat

contents. Certain strains of laying hens were more susceptible than others, however, with most strains it was not uncommon to see signs of the condition. While liver hemorrhages have been significantly reduced in laying hens with introduction of canola meal, isolated cases are seen when feeding 10% or more of this product. Research to date suggests that this is the result of intact glucosinolates, rather than any of their products of hydrolysis. However, it is still unclear how glucosinolates function in the etiology of hemorrhagic liver.

An increase in weight of the thyroid still occurs following feeding of canola meal, although severity is much reduced from that seen with the older rapeseed varieties. Thiocyanate is responsible for the goitrogenic effect noted with these products due to their effect on iodine uptake and metabolism, and so increase in thyroid size is seen. Because thiocyanate is the end product of indole glucosinolate hydrolysis and levels of this compound are still high in canola, then this product probably accounts for the enlarged thyroids still seen with low glucosinolate meals.

Another major problem with the feeding of rapeseed or canola meal is egg taint which is experienced in certain flocks of layers, and especially brown egg layers containing Rhode Island Red ancestory. This is the result of a single major autosomal semi-dominant gene being present which is responsible for the bird lacking the ability to oxidize trimethylamine (TMA) to TMA oxide which is the odorless excretory product of TMA. While the double low varieties of canola contain very low levels of glucosinolates, there is still sufficient present, along with the soluble tannins, to impair TMA oxidation and thus tainted eggs can result. Because brown-egg layers are quite common in many parts of the world, canola meal, in such regions is used sparingly for layers.

Nitrates **–** The nitrate content of cereals and plant proteins can vary from 1-20 ppm. While having little affect on the bird *per se*, reduction to nitrite, usually by intestinal microbes, can lead to toxicity. Nitrite is readily absorbed from the gut and diffuses into red blood cells where it oxidizes the ferrous iron of oxyhemoglobin to the ferric state, forming methemoglobin, which is unable to transport oxygen. Because there has been an interest in the role of dietary nitrite in the incidence of pulmonary hypertension and spontaneous turkey cardiomyopathy. Feeding broilers nitrite up to 1600 ppm had no effect on pulmonary hypertension. However, turkey poults fed 1200 ppm nitrite had a numerically higher incidence of STC than did controls (20 vs. 5%). Interestingly, both chicks and poults developed anemia; poults appeared to be more sensitive to the adverse effects of nitrite on hemoglobin content since the minimum dietary level-causing anemia was 800 ppm in poults and 1200 ppm in chicks. Decreased perormance was observed with the highest dietary concentration. The results of this study indicate that the dietary levels causing methemoglobinemia, anemia, and decreased body weight are not likely to be encountered in cereal grains and legume seeds. However, nitrate and nitrite may also be present at significant levels in water sources.

Tannins – These are water soluble polyphenolic plant metabolites that are known to reduce the performance of poultry when fed at moderate levels in a diet. Grain sorghum is probably the most common feedstuff which contains relatively high levels of tannin. However, faba beans, rapeseed and canola meal all contain sufficient tannins to affect poultry performance.

The growth depressing effect of tannins is undoubtedly due to their ability to bind proteins. Tannic acid is hydrolyzed by the chick to gallic

acid, its major hydrolytic product, and to a lesser extent to the somewhat toxic compounds, pyroacetol and pyrogallol. A large portion of the gallic acid is methylated and excreted in the urine as methyl gallic acid. This pathway offers a possible explanation as to why additions of methionine, choline and other methyl donors have been reported to be beneficial when included in diets containing tannic acid.

Much of the work on toxicity of tannins has involved purified tannic acid. Legume and cereal tannins are of a condensed type while tannic acid is of a hydrolyzable type. Since there are conflicting reports on the degree of growth depression and the role of methionine in alleviating tannin toxicity, it follows that the predominant detoxification process may differ between these two compounds. More recent work suggests that while gallic acid is the breakdown product of both condensed tannins and tannic acid, and can be detoxified by methyl groups, the stability of condensed tannins is such that this route of detoxification may be of little importance.

i) Sorghum tannins - The nutritive value of sorghum is usually considered to be 90 to 95% that of corn, due in large part, to its tannin content. There are a number of varieties of sorghum on the market which are usually classified as bird resistant or non-bird resistant varieties. These have either a low (less than 0.5%) or high (1.5% or higher) level of tannins. A number of toxic effects have been reported with the feeding of high tannin sorghum. These include depressed growth and feed utilization, reduced protein digestibility, lower egg production and leg abnormalities with broilers.

A number of procedures have been tried in an attempt to reduce the toxicity of the tannins in sorghum. These include soaking in water or alkali solution, which are reported to deactivate tannins and thus improve the nutritive value of the cereal. Besides the addition of the methyl donors which have been reported to improve the feeding value of high tannin sorghum, products such as polyvinylpyrrolidone, and calcium hydroxide, or a slurry of sodium carbonate have also been reported to give positive responses. However, several crude enzyme preparations that have been tried were not effective in enhancing the feeding value of high tannin sorghum.

Tannins have also been implicated in egg yolk mottling. Yolk mottling is a condition which periodically appears in a flock and without a direct involvement of nicarbazin, gossypol or certain worming compounds, there is usually no ready explanation for its appearance. While several reports have suggested tannic acid and its derivatives as possible causes, other than the addition of commercial tannic acid at levels above 1%, there appears to be no mottling seen with diets containing up to 2.5% tannins.

There are reports suggesting that tannins are bound tightly to a fraction of the nitrogen in sorghum and that this reduces protein digestibility. However, because the tannins are relatively insoluble they appear to have little influence in complexing with protein. In a recent study with turkeys, a high tannin sorghum variety when used at 40% in the diet, resulted in depressed performance to 8 weeks of age. However, the feeding of a similar level to turkeys beyond 8 weeks of age had no detrimental effects. The authors suggest that a more fully developed digestive system of the older birds may be able to overcome the anti-nutritional effects of the tannins.

While dark colored varieties of sorghum seed usually contain higher levels of tannin than do lighter colored varieties, seed color, in general, is a poor indicator of the tannin content of sorghum.

ii) Faba Bean Tannins - Raw faba beans are known to result in depressed performance of poultry while autoclaving results in a significant improvement in bird performance. Dehulling also results in improved energy value with this effect being greater than can be accounted for by reduction in fiber content. The growth depressing properties of faba beans are due to two water-acetone soluble fractions, one containing low weight polyphenolic compounds, the other containing condensed tannins, the latter being the major growth inhibiting substance. These condensed tannins are similar to those found in sorghum and are concentrated in the hull fraction.

While proper heat treatment of faba beans can markedly increase their nutritive value, there appears to be some detrimental effect on intestinal villi structure regardless of the degree of heat treatment or the fraction of seed consumed. This has led to reports that factors other than those usually considered, such as protease inhibitors, phytates and lectins, may be contributing to the low nutritional value of faba beans. Tannin-free varieties of faba beans are available that contain less than 0.1% condensed tannins in their hulls compared to over 4% in the high tannin varieties. These lighter colored seeds are of improved nutritive value. Regardless of tannin content, appropriate heat treatment improves the nutritive value of faba beans.

iii) Rapeseed and Canola Tannins - Rapeseed and canola meal have been reported to contain 2 to 3% tannin, which is concentrated in the hull. These tannins have been shown to contribute to the egg taint problem of these meals, when fed to brown-egg layers, due to their inhibitory effect on trimethylamine oxidase. The original method for assaying tannin also included sinapine. Because the sinapine content of canola is around 1.5%, a value of 1.5% for total tannins is more realistic than earlier reported values of around 3%. With tannins concentrated in the hull of both rapeseed and canola, the amount of extractable tannins has been investigated and appears to range from 0.02 to 2%. The ability of these tannins to inhibit amylase *in-vitro* was not detected. Hence, it has been assumed that the tannins in rapeseed and canola are bound in such a manner that their influence on digestibility of other ingredients is negligible.

Lathyrism - As with many species of animals, poultry are susceptible to lathyrism, a metabolic condition caused by the consumption of legume seeds of the genus Lathyrus, of which sweet peas are a member. The seeds are rich in protein (25 to 27%) and their availability and relatively low cost in many Asian and mid-Eastern countries often results in their use in poultry feeds. The causative agents for lathyrism are the lathyrogens, of which lathyrogen beta-aminopropionitrile (BAPN) is the principle toxin found. However, there are some synthetic lathyrogens available that have been used in studying the condition.

Lathyrism manifests itself in two distinctive forms. Firstly, there is a disorder of the nervous system leading to a crippling condition and referred to as neurolathyrism, and secondly a disorder of the collagen and elastin component of connective tissue resulting in a skeletal and/or vascular disease and referred to as osteolathyrism. Typical symptoms seen with poultry consuming significant quantities of toxins are depressed performance, ruffled feathers, enlarged hocks, curled toes, ataxia, leg paralysis and eventually mortality.

Most of the poultry research involves specific synthesized lathyrogens rather than natural seeds. BAPN has been shown to inhibit cross-linking

compounds in elastin and collagen by inhibiting the enzyme lysyl oxidase, an important component in the synthesis of these compounds. It has also been reported to reduce growth rate of chicks, poults and ducklings and to reduce egg production of adults of these species. BAPN can result in defective shell membranes, so ultimately affecting shell calcification, leading to malformed and soft-shelled eggs. This effect is similar to that seen with copper deficiency since the enzyme lysyl oxidase is a metalloenzyme that requires copper. Consequently, there are reports of copper alleviating the symptoms of BAPN toxicity.

While recommended maximum levels of inclusion of the various lathyrus seeds, to avoid metabolic problems, varies with the type of seed and the lathyrogen content of the seed, a general recommendation would be to keep the dietary level of BAPN below 50 mg/kg of diet. While the addition of lathyrogens to a laying diet results in a decrease in production after 4 to 5 days, hens seem to return to normal production in 10 to 14 days after receiving a normal diet. Interestingly there has been some research interest on the ability of BAPN to tenderize meat from spent hens. This is obviously related to its effect in altering collagen cross-linking by inhibiting the enzyme lysyl oxidase.

Gossypol - The use of cottonseed products in diets for laying hens has long been a problem for nutritionists as well as producers. As early as 1891 there were reports of mottled egg yolks resulting from the feeding of cottonseed meal to layers. In the early 1930's gossypol was identified as the compound involved in discoloration of egg yolks when hens were fed cotton seed meal. It soon became evident that there were two problems that could occur with the feeding of cottonseed meal to layers: the albumen of stored eggs developed a pink color and thus the disorder became known as pink egg white; and secondly there was brown or olive pigment in the yolks. This later defect was the result of gossypol from the cottonseed pigment glands interacting with iron in the egg yolk.

Although pink albumen discoloration is known to occur spontaneously, it is usually seen with ingestion of products from plants of the botanical order, *Malvales*. Two naturally occurring cyclic fatty acids have been isolated from plants known to cause the unusual color. These compounds were called malvalic and sterculic acids. A color test developed many years ago by Halpen, can be used to identify cottonseed oil in vegetable oil mixtures. The test has been shown to be very specific to cyclopropenoid compounds, especially malvalic and sterculic fatty acids. The pink-white albumen condition noted in stored eggs, which is common with the ingestion of either malvalic or sterculic fatty acids, results from a combination of conalbumen and egg white protein mixing with iron that diffuses from the yolk. This is due, in part, to changes in membrane permeability and an increase in yolk pH. The amount of these compounds fed, storage conditions and breed of hen, have all been shown to influence the degree and incidence of the condition.

Yolk discoloration is also caused by the ingestion of gossypol and/or malvalic or sterculic acid. However, there is a difference in incidence and degree of discoloration and mottling depending on whether intact gossypol or the fatty acids are involved. Changes in membrane permeability and a shift in yolk and albumen pH result in water and albumen protein migrating to the yolks. The severity of the condition will depend on the amount of gossypol ingested and can lead to pasty custard-like or viscous yolks being observed. These can be seen at ovulation but the condition can

be accentuated with storage. There are reports of increased embryo mortality during the first week of incubation when breeders are fed high levels of malvalic or sterculic acid, however, the levels fed must be much higher than those normally present in laying hen diets.

Although varieties of cottonseed have been developed that are gossypol free, their low yield has meant that they are not widely used in commercial production. Consequently, much of the cottonseed grown world-wide still contains appreciable quantities of gossypol. Processing method can markedly reduce the gossypol content of the meal to levels less than 0.04% free gossypol. In addition, soluble iron salts can be added to diets containing cottonseed meal. The iron will complex with gossypol reducing its toxic effects. In a recent report, broilers fed a diet with up to 30% cottonseed meal, with soluble iron added (to provide a 2:1 ratio of iron to free gossypol) resulted in no detrimental effect on weight gain or liveability.

Alkaloids - Alkaloids are found in a number of feedstuffs but by far the most important are the lupine legumes. Seeds of the plant *Crotalaria retusa* L., contain up to 4.5% of the pyrolizidine alkaloid monocrotaline and these can be a problem in cereal contamination in some areas of Asia and Australia. The older varieties of lupines were often referred to as bitter lupines, due to the presence of significant quantities of quinolizidine alkaloids, mainly lupanine. These alkaloids affect the central nervous system causing depressed laboured breathing, convulsions and death from respiratory failure. Newer varieties of lupines now being grown are very low in alkaloids (less than 0.02%) and have been shown to be well tolerated by poultry.

One of the most common sources of alkaloids finding its way into animal feeds is grain contaminated with ergot. Samples of ergot can run as high as 0.4% total alkaloids. Chickens receiving 1 to 2% of ergot in their diet can show symptoms ranging from depressed growth to necrosis of the extremities, staggers, ataxia, tremors and convulsions.

c. Autointoxication

Autointoxication could be defined as self-poisoning as it is endogenous in origin and results from the absorption of waste products of metabolism or from products of decomposition in the intestine. High fiber diets fed to young chicks can cause obstruction of the digestive tract with subsequent absorption of products of decomposition or metabolic wastes. Litter consumed by chicks or over-consumption of green grass or plants can also lead to gut impaction problems.

The chilling or overheating of chicks can lead to vent pasting and occlusion resulting in stasis of the intestine contents with autointoxication being the end result. Birds suffering from autointoxication are anorexic, and show increased water consumption, followed by weakness and prostration. A generalized toxaemia may result leading to nervous symptoms prior to death.

d. Bacterial toxins

Although losses in birds due to bacterial toxins are not of great economic importance, they do occasionally result in heavy losses in a particular flock. The main organism affecting poultry is *Clostridium botulinum*. No significant lesions are found in botulism poisoning and a positive diagnosis is usually based on identification of the organism and its toxin.

Botulism is caused by the toxin produced from the *C. botulinum* organism under anaerobic conditions. *C. botulinum* is a saprophyte found in soil and dirt and can also be found in intestinal contents and feces. The mere presence of the organism is sufficient to cause disease or to be of diagnostic significance. Growth of the organism, in anaerobic conditions, results in the production of toxins. Botulism can result from birds eating carcasses of birds which have died from the disease and also fly larvae from such carcasses. The toxins present in the meat are ingested by larva rendering them extremely poisonous. Symptoms may appear within a few hours to a day or two after contaminated feed is eaten. The common symptom noted is paralysis, with the leg and wing muscles first affected. If the neck muscles are affected the head hangs limp, hence the name 'limberneck' which has been used to refer to the disease. In mild cases, leg weakness, ruffled feathers and soft pasty feces may be noted. The severity of the disease depends on the amount of toxin consumed. However, death usually occurs as this toxin is very potent. Losses in birds are most commonly due to type A and C toxins. Type A, is common in the mountainous regions of North and South American, while type C is world-wide in distribution.

For many years, a disease of wild ducks and other aquatic birds was common in the western part of North America. It is now known that this is due to botulism poisoning. Insect larvae in an aquatic environment may die as the result of anaerobic conditions caused by decaying vegetation. When these larvae are eaten by birds, botulism organisms invade tissues and produce toxins. Prevention relates to proper management procedures that eliminate dead and decomposed carcasses around a poultry house. A good rodent and fly control program is also essential as is screening of the building to eliminate entry of wild birds.

e. Chemotherapeutic drugs

While the use of various pharmaceutical compounds has contributed significantly to the development of the modern poultry industry, their misuse can result in toxicity. Some of the more common drugs that can result in problems if used at toxic levels are:

i. Sulfonamides – Toxicity is manifested by signs of ruffled feathers, paleness, poor growth and increased blood clotting time. Hemorrhages in skin and muscle may be noted and necrosis of the liver, spleen, lungs and kidney are often seen.

ii. Nitrofurans – Toxicity results in depressed growth and hyperexcitability, where chicks cheep and dash about. Enteritis and congestion of the kidneys and lungs, along with body edema and cardiac degeneration may be noted.

iii. Nicarbazin – Toxicity in chicks results in birds being listless and showing signs of ataxia, with incoordination and a stilted gait especially in hot weather. Fatty degeneration of the liver may be noted. The most common problem with nicarbazin is its effect on laying hens. Brown eggs will be depigmented and yolk mottling may be noted with white and brown eggs.

f. Toxic seeds

Phytotoxins can be considered as any toxic substance derived from plants including roots, stems, leaves, flower and seeds. Some plants are toxic throughout the whole growing season while others are only toxic during certain stages of development. The majority of toxic plants are relatively unpalatable and are usually avoided by birds. However, with the absence of succulent feed, range birds will consume sufficient foliage or seeds to result in poisoning. Some of the more common poisonous plants are as follows:

i) Black locust *(Robinia pseudoacacia)* – The toxin is the glycoside robitin-alectin (hemagglutinin). It has been reported that the leaves of black locust are toxic during early July and August in the N. Hemisphere and cause mortality with chickens if consumed at this period. Symptoms noted are listlessness, diarrhea, anorexia and paralysis with death occurring within several days. Hemorrhagic enteritis may also be seen.

ii) Castor bean *(Ricinus communis)* – Many legume seeds contain a protein fraction which is capable of agglutinating red blood cells. These compounds are referred to as lectins and they vary widely in their degree of specificity to types of red blood cells and also their degree of toxicity. Such legumes must be degraded by heat treatment in order to detoxify them and so enhance their nutritive value. Castor bean was one of the first such legumes to be investigated and a lectin called ricin was isolated which is extremely poisonous. However, the steaming of castor meal for 1 hour will reduce the toxicity of the meal to 1/2000 of its original level. Toxicity is seen as progressive paralysis starting with the legs and progressing to complete prostration. With the exception of blood-stained mucus in the droppings, clinical signs are indistinguishable from those of botulism. A pale swollen mottled liver is often seen with petechial hemorrhages present on the heart and visceral fat.

iii) Coffee bean seed *(Cassia occidentalis; C. obtusifolia)* – Mechanical harvesting methods have increased the danger of contamination of corn and soybeans with coffee bean plants which are frequently found in relatively large numbers in the southern USA. At all levels of incorporation of the anthraquinone lectins from coffee seeds, egg production and weight gain are reduced. Platinum colored yolks and profuse diarrhea are also noted with layers. Birds fed 2 to 4% of the coffee seeds become ataxic or partially paralysed before death. Muscle lesions are similar to those seen with vitamin E deficiency. Death often occurs due to a hyperkalemic heart failure. Production will return to normal with the removal of the contaminated feed.

iv) Corn cockle *(Argostemma githago)* – Corn cockle is often harvested with wheat and so can become incorporated into poultry feeds. The diet must contain 5% or more of corn cockle to show toxic symptoms, which are caused by githagenin, a plant saponin. General weakness, with decreased respiration and heart rate may be noted often associated with diarrhea. Hydropericardium and edema of the intestine can be seen along with petechial hemorrhages in the myocardium and congestion and degeneration of the liver.

v) Coyotillo *(Karwinskia humboldtiana)* – This plant is indigenous to southwest Texas and Mexico. The fruit and seed are toxic to poultry and 3 to 4 days after ingestion generalized toxaemia signs can be noted, followed by paralysis and death.

vi) Cacao *(Theobroma cacao)* – High levels of cacao bean wastes (in excess of 7% of the diet) are required to show toxic symptoms caused by the toxin theobromine. Such symptoms include nervous and excitable birds. Birds die in convulsions and usually are on their back with legs drawn tightly against their body. The comb is often cyanotic.

vii) Crotalaria seed – A few species are toxic to poultry the most problematic being C. *spectabilis* and *C. giant (striata)*. The toxin is a pyrolizidine alkaloid, designated, monocrotaline. Crotalaria is a small black or brownish seed and is a contaminant in corn and soybeans in the southeast USA. One percent in a chick diet can result in death by 4 weeks of age. Birds become huddled

having a pale comb and diarrhea and may exhibit a duck-like walk. With young birds abdominal fluid and edema, similar to that seen with ascites may be noted. With mature birds, there is a reduced egg production and massive liver hemorrhages may be noted. The lesions are similar to those reported for toxic fat and salt poisoning.

viii) Daubentonia seed *(Daubentonia longifolia)* – This seed can be a problem in the southern USA. As little as 9 seeds can cause death in 24 – 72 hours. The comb can be cyanotic, with the head hanging to one side. Emaciation and diarrhea may also be noted. Severe gastroenteritis, ulceration of the proventriculus and degeneration of the liver are not uncommon.

ix) Glottidium seed *(Glottidium vesicarium)* – This seed is often found in the southeastern USA. Clinical symptoms are a cyanotic comb and wattles, ruffled feathers, emaciation and yellow diarrhea. Necrotic enteritis as well as liver and kidney degeneration are also common observations.

x) Death camas *(Zygadenus)* – This is a green range plant with an alkaloid toxin called nuttallii. Consumption of 5 to 10 g by a chicken can result in clinical symptoms in 12 hours that include incoordination, diarrhea and prostration followed by death.

xi) Vetch *(Vicia sativa)* - Vetch belongs to the Leguminosae family which is related to the legumes Lathyrus, Pisum and Ervum. It is common in the northwest USA and produces a cyanogenic glucoside called viciana, which is converted by the enzyme vicianase into hydrocyanic acid. Problems comparable to lathyrism are observed, including excitability, incoordination, respiratory problems and convulsions.

xii) Milkweed – Two common species are *Asclepias tuberosa* and *A. incarnata*. They contain the bitter glucoside, asclepdin, which is toxic to birds. Symptoms vary widely depending on the quantity of material consumed. The first sign is usually lameness, developing quickly into complete loss of muscle control. The neck becomes twisted with the head drawn back. In some cases symptoms gradually subside. In fatal cases, symptoms become more progressive and prostration, coma and death result. No characteristic lesions are seen on necropsy.

xiii) Algae – Certain types of algae, including *Microcystis aeruginosa*, which readily grows in many lakes, can become concentrated by wind and deposited on shore or in shallow water. Degradation of this material produces toxins which have been responsible for losses in wild and domestic birds. The condition is usually noted in summer months. Toxicity is proportional to the amount of toxin consumed. Death can result in 10 to 45 minutes for mature ducks and chickens. Clinical symptoms include restlessness, twitching, muscle spasms, convulsions and death. These symptoms are similar to those seen with strychnine poisoning.

2.5 FEED MANUFACTURE

In the early days of poultry nutrition feeds contained relatively few synthetic ingredients and the smallest amount of any addition amounted to 0.5% or more. Some natural ingredients, however, have been gradually replaced and supplemented by extremely small quantities of synthetic and purified ingredients, especially the vitamins, trace minerals, pigments and various pharmacological compounds. Consequently, the proper mixing of feed requires ever increasing technical knowledge. Improper mixing can result in variation in the quality of feed and vitamin or mineral deficiencies resulting in lack of protection against disease or chemical or drug toxicity.

a. Vitamin-Mineral Premixes

Micro-ingredients should be properly premixed before being added to a feed. It is desirable to have similar physical characteristics among ingredients to be premixed. The diluent suggested for use in the vitamin-mineral premixes is ground yellow corn or wheat middlings, both being of medium grind for best results. If the carrier is too coarse, it is not possible to obtain good distribution of the supplements, while too fine a carrier leads to dustiness and caking. For mineral mixes, limestone or kaolin (china clay) make satisfactory carriers. Where premixes are being stored for relatively short periods of time, the vitamin and mineral premix can be combined. However, where mixes are to be stored for more than 6 weeks in a warm moist environment, it may be advisable to make separate vitamin and mineral mixes. Also, if premixes are to be shipped long distances and thus subjected to a great deal of handling, and perhaps high temperature, it is advisable to make separate vitamin and mineral mixes. This helps to reduce the physical separation of nutrients and leads to less vitamin deterioration.

When vitamin-mineral premixes are prepared in quantity ahead of time, they should be clearly labeled and stored in a cool dry place for future use. With the addition of an antioxidant and the margins of safety provided in most premixes, they can be held for two to three months under ideal conditions. Rather than suggesting the use of products with specific potencies to supply the vitamins and other nutrients (Table 2.26) the units or weights of the compounds have been indicated and the decision as to product use is left to the individual. Some feed manufacturers are capable of making premixes from more concentrated vitamin and mineral preparations, since this usually results in a cost saving compared with the use of more dilute preparations. The choice of potency of products for use in the premixes should be governed, to a large extent, by personnel and the facilities available. Because vitamin and mineral supplements represent a relatively small part of the total cost of a diet, margins of safety are being added in most cases. Lower levels can be used with satisfactory results under ideal conditions.

The direct addition of vitamin premixes or other supplements to the feed, at a usage rate less than 1 kg/tonne, is not usually recommended. These micro-ingredients should be suitably premixed first, so that at least 1 kg/tonne is added. It is generally recommended that vitamin-mineral premixes be added to the mixer after about one-half of the other ingredients have been included. The time required for a satisfactory mix is very important and varies considerably depending upon the equipment used. Usually 2 – 3 minutes is the optimum for horizontal mixers and up to 5 minutes for vertical machines although mixing times are being continually reduced with newer equipment. This can vary with the type of mixer and manufacturer's specifications should always be followed.

Table 2.26 Vitamin-mineral premixes (without choline)
– all premixes should be made up to 1 – 5 kg by the addition of a carrier such as wheat middlings. The amounts shown below are the levels of nutrients to be added per tonne of finished feed.

	CHICKEN				TURKEY			WATERFOWL		
VITAMINS	Starter	Grower	Laying	Breeder	Starter	Grower	Breeder	Starter	Grower	Breeder
Vitamin A (M.IU)	10.0	8.0	7.5	11.0	10.0	8.0	11.0	10.0	8.0	10.0
Vitamin D_3 (M.IU)	3.5	3.3	3.3	3.3	3.5	3.3	3.3	2.5	2.5	3.0
Vitamin E (T.IU)	30.0	20.0	50.0	70.0	40.0	30.0	100.0	20.0	15.0	40.0
Riboflavin (g)	6.0	5.0	5.0	8.0	6.0	5.0	8.0	5.0	4.0	5.5
Thiamin (g)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Pyridoxine (g)	3.3	3.3	3.3	5.0	3.3	3.3	5.0	3.3	3.3	3.3
Pantothenic acid (g)	15.0	10.0	10.0	15.0	15.0	12.0	15.0	12.0	10.0	10.0
Vitamin B_{12} (g)	.015	.012	.015	.015	.015	.012	.015	.015	.010	.015
Niacin (g)	50.0	30.0	40.0	50.0	50.0	40.0	50.0	50.0	40.0	50.0
Vitamin K (g)	2.0	2.0	2.0	3.0	2.0	2.0	3.0	1.5	1.5	1.5
Folic acid (g)	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	0.5	0.5
Biotin[1] (g)	0.15	0.10	0.10	0.15	0.2	0.15	0.2	0.1	0.1	0.1
MINERALS										
Manganese (g)	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Zinc (g)	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Copper (g)	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Selenium (g)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Iron (g)	50	40	30	40	50	40	40	40	30	30

All vitamin premixes should contain Ethoxyquin to provide 125g/tonne feed.
[1] Increase if diet contains > 10% wheat.

The segregation of ingredients in a mixed feed can occur due to improper handling after mixing. This can be a problem when mash feeds containing no added fat are blown into bulk bins. However, care in unloading and a cyclone on top of the bulk tank will help overcome the problem. This is usually not a great problem when the feed is pelleted or crumbled.

b. Vitamin Stability

Naturally occurring vitamin E is quite unstable, particularly in the presence of fat and trace minerals, however, vitamin E added as a supplement usually is in a highly stable form (e.g. gelatin coated beadlet containing an antioxidant).

Vitamin A in fish oil and pro-vitamin A compounds in yellow corn are easily destroyed in the typical mixed ration. Most dehydrated green feeds are now treated with an antioxidant that helps prevent the destruction of the pro-vitamin A compounds during storage. Today, most poultry feeds contain supplementary gelatin- or starch-coated synthetic vitamin A which is quite stable. The inclusion of antioxidants in the feed helps to retain the potency of vitamins A and E in mixed feed.

Vitamin D_3 is the only form of the product to be used in poultry diets, since birds cannot metabolize vitamin D_2. Vitamin D_3 supplements are available in a dry, stabilized form. These products are reported to be stable when mixed with minerals. Hy-D®, a commercial form of $24(OH)D_3$ is also very stable within premixes and mixed feed.

Calcium pantothenate may be destroyed in the presence of supplements containing acid ingredients such as niacin, arsenilic acid and 3-nitro. The calcium chloride complex of calcium pantothenate is more stable than is conventional calcium pantothenate under acid conditions.

Recent work has shown that thiamin, folic acid, pyridoxine and some vitamin K supplements can be relatively unstable in the presence of trace mineral supplements. This is especially true where the minerals are supplied as sulphate salts, hence special consideration must be given to the above mentioned vitamins when premixes contain both vitamins and minerals, and storage is for 4 – 6 weeks.

Most of the other vitamins are fairly stable. However, care should be taken in storing vitamins to ensure their potency. Always store in a cool, dry, lightproof space or container. While vitamin supplements are an extremely important part of a well balanced diet, animals usually have sufficient body stores to meet their requirements for several days. Modern poultry farms receive feed deliveries on a weekly or even more frequent basis. Failure to incorporate the vitamin premix in a delivery of feed will likely have little or no effect on the performance of most classes of poultry, assuming the ‘next delivery’ contains the vitamin supplement. For breeding birds, this may not be true, especially for riboflavin, which could well affect hatchability if hens are fed a deficient diet for 5 to 7 days.

c. Pelleting

The pelleting process usually involves treating ground feed with steam and then passing the hot, moist mash through a die under pressure. The pellets are then cooled quickly and dried by means of forced air. Sufficient water should be applied so that all feed is moistened. Pelleting at too low a temperature, or with too little steam, results in a ‘shiny pellet’, due to increased friction on the pellet going through the die. Often such pellets are only the original mash enclosed in a hard capsule and have not benefited from the ‘cooking’ process brought about by moisture and heat.

Optimum moisture content of a feed required for good pelleting will vary with the composition of the feed, however, a range of 15 to 18% moisture is usually desirable. Feeds containing liberal quantities of high fiber ingredients will require a higher level of moisture while feeds low in fiber will require less moisture. A good pellet, when hot, can be reduced to two-thirds of its length without crumbling. Such feed has been 'steam-cooked' and holds together well. Rations can be pelleted at any temperature up to 88ºC that will allow for maximum production per hour without any major fear of vitamin destruction.

Feed mills sometimes experience difficulty in obtaining good pellets when manufacturing corn-soybean diets containing added fat. Products such as lignosol or bentonite are reasonably effective as binding agents, however, they a have little nutritive value, and so one should consider whether the advantage of introducing such material into pelleted or crumbled diets warrants the cost. The inclusion of 10 to 15% of wheat, wheat middlings or to a lesser extent barley will often give a pellet of satisfactory hardness. When these ingredients are too expensive, the addition of about 2% of extra water to the mash will aid in producing a better pellet. If this procedure is followed, however, extra drying of the pellets is required so that mold growth does not occur during storage. Work in our laboratory has indicated that molasses may be used as a pellet binder. In addition to aiding in pelleting, molasses unlike other binders, also contributes energy to the diet and so inclusion levels of 1 to 2% in certain diets may be beneficial.

In addition to the advantages of less feed wastage and ease of handling, pelleted diets are more efficiently utilized by poultry. While some of this improvement is due to chemical changes brought about by heat, moisture and pressure, a significant part of the enhanced efficiency is due to birds spending less time when eating pellets resulting in a reduction in maintenance energy requirements by the bird. This situation was demonstrated in the classical study by Jensen *et al.* (Table 2.27).

Table 2.27 Time spent eating mash and pelleted diets

AGE	*Av. time spent eating (min/12 hr day)*		*Av. feed consumed (g/bird/12 hr)*	
	Mash	*Pellets*	*Mash*	*Pellets*
Turkeys				
(38-45 d)	136	16	62	57
Chickens				
(21-28 d)	103	34	38	37

Jensen et al. (1962)

The need for good quality pellets is often questioned by feed manufacturers since regrinding of pellets or crumbles and feeding these to birds has little apparent effect on performance.

There seems little doubt that good quality crumbles and pellets can be advantageous for improving the growth rate of turkeys. However, pellet quality seems of less importance with broiler chickens, especially where high-energy diets are considered. More important in the pelleting process is the treatment of feed with steam and pressure, although it is realized that in certain markets it is difficult to sell feed that is not of 'ideal' pellet quality.

d. Expanding, extrusion and thermal cooking

Extrusion has been used for a number of years to produce dry cereal snack foods and more recently, various pet foods. Extrusion usually involves higher temperatures and pressure than does conventional steam pelleting, and so there is greater

potential for starch gelatinization and theoretically higher digestibility. Extrusion is however much slower than conventional pelleting, and initial capital cost is very high.

Thermal cooking offers the most extreme processing conditions, where high temperatures can be maintained for very long periods of time, relative to pelleting, extrusion or expansion. Thermal cooking will result in the best possible starch gelatinization etc. and will also give the best control over microbial content.

While all heat processing conditions are going to reduce microbial counts in feed there will be a concomitant loss of heat-sensitive nutrients such as some vitamins and amino acids. In this context synthetic amino acids may be more susceptible to heat processing than those naturally present in other ingredients. One recent study suggested some 6% loss of total methionine in an extruded broiler starter that contained 0.18% supplemental methionine. For most vitamins, other than vitamin C and MSBC, normal pelleting conditions are expected to result in 8 – 10% loss of potency. Extrusion however, which usually employs much higher temperatures, can lead to 10 – 15% loss of most vitamins. Under any heat treatment conditions there will always be significant loss (□ 50%) of regular forms of vitamin C, and up to 30 – 50% loss of MSBC (Table 2.28).

Table 2.28 Effect of steam pelleting, extrusion and expansion on loss of vitamin potency

	Loss of Vitamin Potency (%)		
VITAMIN	*Pelleting (82ºC, 30 sec)*	*Expander (117ºC, 20 sec)*	*Extrusion (120ºC, 60 sec)*
Vitamin A (beadlet)	7	4	12
Vitamin D_3 (beadlet)	5	2	8
Vitamin E	5	3	9
MSBC	18	30	50
Thiamin	11	9	21
Folic acid	7	6	14
Vitamin C	45	40	63
Choline chloride	2	1	3

Adapted for Coehlo, (1994)

2.6 WATER

Water, is the most critical nutrient that we consciously supply to birds, yet in most instances, it is taken completely for granted and often receives attention only when mechanical problems occur. Water is by far the largest single constituent of the body, and represents about 70% of total body weight. Of this body water, about 70% is inside the cells of the body and 30% is in the fluid surrounding the cells and in the blood. The water content of the body is associated with muscle and other proteins. This means that as a bird ages, and its body fat content increases, then its body water content expressed as a percent of body weight will decrease. The bird obtains its water by drinking, from the feed and by catabolism of body tissues which is a normal part of growth and development.

a. Water intake

Water intake of a bird increases with age, although it decreases per unit of body weight. Drinking behaviour is closely associated with feed intake, and so most factors affecting feed intake will indirectly influence water intake. At moderate temperatures, birds will consume almost twice as much water by weight as they eat as feed. Any nutrients that increase mineral excretion by the kidney will influence water intake. For example, salt, or an ingredient high in sodium, will increase water intake.

Similarly, feeding an ingredient high in potassium such as molasses or soybean meal, or calcium/phosphorus sources contaminated with magnesium, will result in increased water intake. Such increases in water intake are of no major concern to the bird itself, but obviously result in increased water excretion and so wetter manure. Table 2.29 indicates average water consumption of various poultry species maintained at 20 or 32ºC. These figures indicate approximate water usage values and will vary with the stage of production, health and feed composition. As a generalization, for any bird up to 8 weeks of age, an approximation of water needs can be calculated by multiplying age in days x 6 (e.g. 42 d = 252 ml/d).

In calculating the water needs of egg producing stock, it should be realized that water intake is not constant throughout the day, rather it varies depending upon the stage of egg formation (Fig 2.2). These data clearly show a peak in water consumption immediately following egg laying, and again, at the time just prior to the end of a normal light cycle. This means that water needs must be accommodated during these peak times (around 10 – 11 a.m. and 6 – 8 p.m.) within a 6 a.m. – 8 p.m. light cycle, because most birds will be in the same stage of egg formation as directed by the light program.

Fig. 2.2 Water consumption of laying hens in relation to time of oviposition. (from Mongin and Sauveur, 1974)

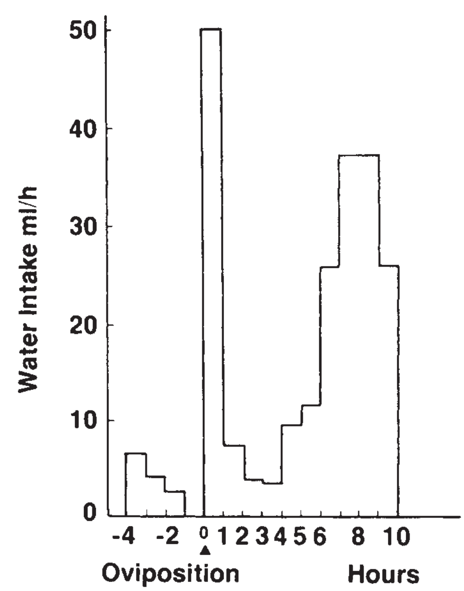


Table 2.29 Daily *ad-lib* water consumption of poultry (litres per 1,000 birds)

		20ºC	*32ºC*
Leghorn pullet	*4 wk*	*50*	*75*
	12 wk	*115*	*180*
	18 wk	*140*	*200*
Laying hen	*50% prod.*	*150*	*250*
	90% prod.	*180*	*300*
Non-laying hen		*120*	*200*
Broiler breeder pullet	*4 wk*	*75*	*120*
	12 wk	*140*	*220*
	18 wk	*180*	*300*
Broiler breeder hen	*50% prod*	*180*	*300*
	80% prod	*210*	*360*
Broiler chicken	*1 wk*	*24*	*40*
	3 wk	*100*	*190*
	6 wk	*240*	*500*
	9 wk	*300*	*600*
Turkey	*1 wk*	*24*	*50*
	4 wk	*110*	*200*
	12 wk	*320*	*600*
	18 wk	*450*	*850*
Turkey breeder hen		*500*	*900*
Turkey breeder tom		*500*	*1100*
Duck	*1 wk*	*28*	*50*
	4 wk	*120*	*230*
	8 wk	*300*	*600*
Duck breeder		*240*	*500*
Goose	*1 wk*	*28*	*50*
	4 wk	*250*	*450*
	12 wk	*350*	*600*
Goose breeder		*350*	*600*

These figures indicate approximate water usage values and will vary with the stage of production, health and feed consumption.

The contribution of feed is not usually considered in calculating water balance, yet most feeds will contain around 10% of free water. Other bound water may become available during digestion and metabolism, such that 7 – 8% of total requirements can originate from the feed.

Water is created in the body as a by-product of general metabolism. If fats are broken down, then about 1.2 g of water are produced from each gram of fat. Likewise protein and carbohydrate will yield about 0.6 and 0.5 g per gram respectively. Total metabolic water can be more easily estimated from the bird's energy intake because on average 0.14 g of water is produced for each kcal of energy metabolized. This means that for a laying hen, consuming 280 kcal ME/day, about 39 g of metabolic water will be produced. Feed and metabolic water together therefore account for about 20% of total water needs, and so are very important in the calculation of water balance.

b. Water output

The quantities of water excreted in the feces and urine are dependent on water intake. Broiler chickens produce excreta containing about 60 – 70% moisture, while that produced by the laying hen contains about 80% moisture. For the laying hen at least, the quantity of water excreted in the feces is about four times that excreted as urine. Undoubtedly, this loss is subject to considerable variation with the amount and nature of undigested feed.

Evaporation is one of four physical routes by which poultry can control their body temperature. Due to its molecular structure and bonding, water has an unusually high latent heat of vaporization. Some 0.5 kcals of heat are required to vaporize one gram of water. Evaporative heat loss takes place mainly through the respiratory tract. The fowl has no sweat glands, consequently evaporation via the skin is minimal. Evaporation overwhelmingly occurs via the moist surface layer of the respiratory tract to the inspired air which is 'saturated' with water vapor at body temperature. Evaporation rate is therefore proportional to respiratory rate. Heat loss through evaporation represents only about 12% of total heat loss in the broiler chicken housed at 10ºC, but this increases dramatically through 26 – 35ºC where it may contribute as much as 50% of total heat loss from the body. At high temperatures, evaporative water loss will approximate water intake and so this obviously imposes major demands on the ventilation systems.

c. Water balance and dehydration

Under normal physiological conditions for adult birds, water intake and output are controlled to maintain a constant level of water in the body. A positive water balance is found in the growing bird to accommodate growth. With drinking water being supplied *ad libitum* under most commercial conditions, dehydration due to lack of drinking water should not occur. The adverse effects of short term reduced water intake are often a result of a concomitant reduction in feed intake.

The turkey poult is most susceptible to dehydration resulting from drinking water deprivation, and mortality occurs when drinking water is re-introduced to the poults. Poults 11 days of age, subjected to a 48-hour period of water deprivation, showed 83% mortality following reintroduction of *ad libitum* cold water, and in most cases death occurred within 30 minutes. Poults 18 days of age showed less mortality which was somewhat delayed (2 –34 hours) while older turkeys subjected to the same conditions showed no

mortality. The exact reason for this mortality is not fully understood. Poults deprived of water show reduced body temperature, and when water is introduced, body temperature continues to decrease for 30 minutes or so. Poults often drink large amounts of water following dehydration, and it has been suggested that the problem relates to simple water intoxication and associated dilution of electrolytes in the body. If young poults are dehydrated for whatever reason, then administration of electrolytes in the water may be beneficial. This problem does not seem to occur with chickens.

d. Drinking water temperature

Water offered to birds is usually at ambient temperature. This means that for laying birds housed under controlled environmental conditions, the temperature of drinking water is held fairly constant, while for broiler chickens, water temperature decreases with age corresponding to a reduction in brooding temperature. It is only for the first few days of a chick's life that drinking water temperature is specified, where traditional management recommendations suggest the use of 'warm' water. However, there is little documented evidence supporting this recommendation. Birds drink more water at higher environmental temperatures, yet the cooling of water may result in even higher intakes. Table 2.30 outlines the results of a small scale study conducted with layers housed at 33°C.

Table 2.30 Layer performance at 33°C with hot vs cold drinking water

	Water temperature	
	33°C	*2°C*
Feed/bird/day (g)	*63.8*	*75.8*
Egg production (%)	*81.0*	*93.0*
Egg weight (g)	*49.0*	*48.5*

When birds received cool water for a 4-week period, they were able to maintain peak egg production, possibly due to higher feed intake. Under commercial conditions, with long runs of water pipe, it is obviously very difficult to duplicate these conditions. However, it does show the importance of trying to keep the water as cool as possible, and in this regard, the usual practice of placing water tanks on high towers in direct sunlight should be seriously questioned.

e. Water restriction

Most birds should have continuous access to water. Some breeders recommend water restriction of laying hens as a means of preventing wet manure, especially in hot climates, although serious consideration should be given to other preventative measures prior to this last resort. Production may drop as much as 30% when hens are deprived of water for 24 hours, and it may take as long as 25 to 30 days before production returns to normal. Similar results have been reported for broilers where decreases in water supply have resulted in marked depressions in weight gain. Table 2.31 shows the results of a controlled test where water restriction was imposed on broilers. There was a marked drop in feed intake with the greatest reduction occurring with the first 10% reduction in water intake, causing a 10% decline in feed intake.

Table 2.31 Effect of water restriction on relative weekly feed consumption of broilers

Age (weeks)	*Degree of water restriction (%)*					
	0	**10**	**20**	**30**	**40**	**50**
2	100	84	84	75	84	71
4	100	99	102	90	85	80
6	100	88	81	78	73	71
8	100	86	83	79	74	67
Total	100	90	87	81	77	73

** All birds receive water ad libitum for first week.*
(Data from Kellerup et al. 1971)

The effect of an accidental 48-hour cut in water supply to layers is shown in Fig. 2.3. Production dropped off very quickly to virtually 0%, although interestingly a few birds maintained normal production. Most birds that resumed production within 28 d achieved normal output for their age, and there was an indication of improved shell quality.

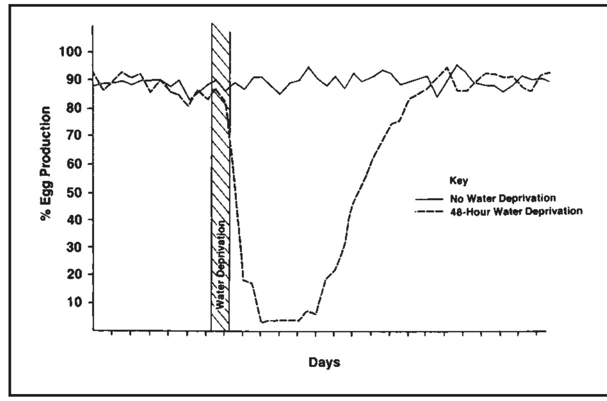
For certain classes of stock, intentional water restriction is used as a management tool. To date, this is most common with broiler breeders fed on a skip-a-day program. Water restriction may occur on both feed-days and off-feed days. Restriction on off-feed days is done because it is assumed that birds will over-consume water on these days due to hunger or boredom. However, it seems as though breeders do not drink that much water on an off-feed day (Table 2.32).

Table 2.32 Water intake of 13 week-old broiler breeders (ml/bird/day)

	Water restricted		*Ad-lib water*
	each day	*only on feed days*	
Feeding day	*175*	*182*	*270*
Non-feed day	*108*	*109*	*36*
Average	*141*	*145*	*153*

All birds drank the same average amount of water over a 2 day feeding schedule regardless of water treatment. When birds are given free-choice water, they obviously over-consume on a feed-day, but drink little on an off-feed day. These data suggest the need for water restriction of skip-a-day fed birds, although special attention on feed-days rather than off-feed days will be most advantageous in preventing wet litter.

Fig. 2.3 Effect of a 48-hour period of water deprivation on egg numbers.



f. Water quality

Water quality should be monitored with assays conducted at least each 6 months. Chemical contaminants are the most serious problem affecting water quality. However, poultry usually adjust to high levels of certain minerals after a period of time, and so only in a relatively small number of cases does the mineral content of water significantly affect the performance of a flock. There are certain areas where water salinity is high enough to adversely affect flock performance. In such cases, it may be necessary to remove some of the supplemental salt from the diet. However, this should be done only after careful consideration to ensure that there will be a sufficient salt intake because performance can be severely reduced if salt intake is too low.

Any bacterial contamination of water is an indication that surface water is entering the water supply and steps should be taken to correct the situation. Alternatively, the water may be chlorinated to eliminate contamination. Another problem that can exist with water is a

build-up of nitrates or nitrites. Such contamination is usually an indication of run-off from animal wastes or fertilizers leaching into the water system. Although the standard for human water supply is 10 to 20 ppm of nitrate nitrogen, higher levels can usually be tolerated by animals. Levels beyond 50 ppm need to be present before water is suspected as a factor in the poor performance of poultry. As nitrites are 10 times more toxic than nitrates, and because bacteria in the intestinal tract and in the water supply can convert nitrates to nitrites, levels of these two contaminants in the water supply must be kept to a minimum. Superchlorination of the water will quickly oxidize nitrites to nitrates thereby reducing their toxicity. Before initiating a superchlorination program, check with a local pathologist to ensure a proper level of chlorination in order not to interfere with the performance or efficiency of vaccines or other drugs.

Table 2.33 Concentration of water minerals above which problems may occur with poultry (ppm)

Total soluble salts (hardness)	*1500*
Chloride	*500*
Sulphate	*1000*
Iron	*50*
Magnesium	*200*
Potassium	*500*
Sodium	*500*
Nitrate	*50*
Arsenic	*0.01*
pH	*6.0 – 8.5*

Table 2.33 outlines standards for drinking water in terms of mineral levels. Toxicity and loss of performance will vary dependent upon bird age and class of stock, but in general these values can be used as guidelines to indicate the possibility of toxicity with birds consuming such water over prolonged periods.

In the last few years, there has been an interest in the treatment of water for poultry. In large part, this is carried out in an attempt to prevent problems of mineral deposits occurring in pipelines, boilers and automatic waterers, rather than preventing toxicity problems *per se*. Such treatments involves orthophosphates, which sequester calcium and magnesium, thereby preventing precipitation in the water supply. In most situations, these systems will not unduly alter the water composition in terms of the bird's nutritional requirements. As a last resort, some producers use water softeners, and in these situations, there is some cause for concern, regarding the bird's health. These softeners contain an active column of resin, that has the ability to exchange one ion (mineral) for another. Over time, the resin column becomes saturated with the absorbed minerals (usually calcium and magnesium salts) that are extracted from the water, and so it must be flushed and re-charged with the donor mineral. In most softeners, this recharging process involves sodium from NaCl. This means that sodium is replacing other minerals in the water, because sodium salts readily dissolve, and will not leave mineral scale in the equipment. The amount of sodium that is pumped into the water supply is therefore in direct proportion to the hard minerals extracted from the water. In areas of very hard water, one can expect higher levels of sodium in water reaching the birds, and vice-versa in areas of lower water hardness. Problems in water sodium will likely occur if softener salt use exceeds 40 kg/40,000 litres of water.

g. General management considerations with water

Where continuous flow water troughs are used for caged birds, one must be sure that birds at the end of the trough obtain sufficient water. A rise in house temperature will result in increased water consumption, and unless the water supply can be adjusted accordingly, shortages of water may result for the birds at the far end of the line. It has also been demonstrated that poorly beak-trimmed birds may not be able to drink sufficient water to sustain maximum production. When the lower beak of the bird is too long, up to 20% loss in egg production can occur, compared with properly beak-trimmed birds. When disease or stress occur, a decrease in water consumption is usually noted a day or two before a decrease in feed consumption. For this reason, managers should consider installing water meters on all water lines to each pen or cage row and have the attendant keep a daily record of water consumption. Such records can give early warning of potential problems with the flock.

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CHAPTER 3

FEEDING PROGRAMS FOR GROWING EGG-STRAIN PULLETS

3.1 Diet specifications

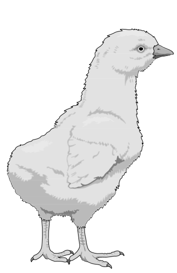


Table 3.1 shows diet specifications for Leghorn pullets, while Table 3.2 provides comparable data for brown egg birds. These nutrient specifications are intended for guidelines in diet formulation when general growth and development (as outlined by the primary breeders) is the goal of the rearing program. Pullets are grown under a range of environmental conditions and housing systems and these can influence nutrient needs. In most situations, variable management conditions influence energy needs, and so it is important to relate all other nutrients to energy level. In hot climates for example, the pullet will eat less and so nutrients, such as amino acids, will have to be increased accordingly. Pullets grown on the floor, rather than in cages, will eat more feed, and so amino acid levels can be reduced. The diet specifications are based on using conventional ingredients where nutrient digestibility is fairly predictable. When non-standard ingredients are used, it is essential to formulate to more stringent standards of digestibility, such as for digestible amino acids. Tables 3.3 – 3.6 show examples of diet formulations using corn, wheat or sorghum with and without meat meal.

Table 3.1 Diet specifications for leghorn pullets

Age (weeks)	Starter (0 to 6)	Grower (6 to 10)	Developer (10 to 16)	Pre-lay (16 to 18)
Crude Protein (%)	20.0	18.5	16.0	16.0
Metabolizable Energy (kcal/kg)	2900	2900	2850	2850
Calcium (%)	1.00	0.95	0.92	2.25
Available Phosphorus (%)	0.45	0.42	0.40	0.42
Sodium (%)	0.17	0.17	0.17	0.17
Methionine (%)	0.45	0.42	0.39	0.37
Methionine+cystine (%)	0.78	0.72	0.65	0.64
Lysine (%)	1.10	0.90	0.80	0.77
Threonine (%)	0.72	0.70	0.60	0.58
Tryptophan (%)	0.20	0.18	0.16	0.15
Arginine (%)	1.15	0.95	0.86	0.80
Valine (%)	0.75	0.70	0.65	0.60
Leucine (%)	1.30	1.10	0.92	0.88
Isoleucine (%)	0.70	0.60	0.51	0.48
Histidine (%)	0.35	0.32	0.29	0.26
Phenylalanine (%)	0.65	0.60	0.53	0.49
Vitamins (per kg of diet):				
Vitamin A (I.U)	8000			
Vitamin D_3 (I.U)	2500			
Vitamin E (I.U)	50			
Vitamin K (I.U)	3			
Thiamin (mg)	2			
Riboflavin (mg)	5			
Pyridoxine (mg)	4			
Pantothenic acid (mg)	12			
Folic acid (mg)	0.75			
Biotin (µg)	100			
Niacin (mg)	40			
Choline (mg)	500			
Vitamin B_{12} (µg)	12			
Trace minerals (per kg of diet):				
Manganese (mg)	60			
Iron (mg)	30			
Copper (mg)	6			
Zinc (mg)	60			
Iodine (mg)	0.5			
Selenium (mg)	0.3			

Table 3.2 Diet specifications for brown egg pullets

Age (wks)	*Starter (0 to 5)*	*Grower (5 to 10)*	*Developer (10 to 15/16)*	*Prelay (15/16 to 17)*
Crude Protein (%)	20.0	18.0	15.5	16.0
Metabolizable Energy (kcal/kg)	2900	2850	2800	2850
Calcium (%)	1.00	0.95	0.90	2.25
Av. Phosphorus (%)	0.45	0.42	0.38	0.42
Sodium (%)	0.17	0.17	0.17	0.17
Methionine (%)	0.45	0.41	0.35	0.34
Methionine+cystine(%)	0.78	0.71	0.63	0.61
Lysine (%)	1.10	0.90	0.75	0.73
Threonine (%)	0.72	0.68	0.60	0.57
Tryptophan (%)	0.20	0.18	0.15	0.15
Arginine (%)	1.15	0.95	0.86	0.80
Valine (%)	0.75	0.70	0.65	0.60
Leucine (%)	1.30	1.10	0.92	0.88
Isoleucine (%)	0.70	0.60	0.51	0.45
Histidine (%)	0.35	0.32	0.27	0.24
Phenylalanine (%)	0.65	0.60	0.50	0.45
Vitamins (per kg of diet):				
Vitamin A (I.U)	8000			
Vitamin D_3 (I.U)	2500			
Vitamin E (I.U)	50			
Vitamin K (I.U)	3			
Thiamin (mg)	2			
Riboflavin (mg)	5			
Pyridoxine (mg)	4			
Pantothenic acid (mg)	12			
Folic acid (mg)	0.75			
Biotin (µg)	100			
Niacin (mg)	40			
Choline (mg)	500			
Vitamin B_{12} (µg)	12			
Trace minerals (per kg of diet):				
Manganese (mg)	60			
Iron (mg)	30			
Copper (mg)	6			
Zinc (mg)	60			
Iodine (mg)	0.5			
Selenium (mg)	0.3			

Table 3.3 Examples of chick starter diets (kg)

	1	2	3	4	5	6
Corn	544	555				
Wheat			628	643		
Sorghum					578	568
Wheat shorts	100	105	100	100	100	100
Meat meal		50		30		50
Soybean meal	310	258	227	191	27	250
Fat	10	10	10	10	10	10
*DL-Methionine**	1.1	1.3	1.5	1.6	1.7	1.6
Salt	3.1	2.8	2.7	2.3	3.4	2.9
Limestone	18	13.2	19.3	16.1	18.5	13.3
Dical Phosphate	12.8	3.7	10.5	5	11.4	3.2
*Vit-Min Premix***	1	1	1	1	1	1
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	21.0	21.0	20.6	20.6	20.0	21.0
ME (kcal/kg)	2930	2930	2900	2930	2930	2930
Calcium (%)	1.05	1.05	1.00	1.05	1.05	1.05
Av. Phos. (%)	0.47	0.47	0.45	0.45	0.45	0.47
Sodium (%)	0.18	0.18	0.18	0.18	0.18	0.18
Methionine (%)	0.46	0.47	0.45	0.46	0.45	0.45
Meth + Cys. (%)	0.78	0.78	0.78	0.78	0.81	0.81
Lysine (%)	1.16	1.17	1.10	1.10	1.10	1.20
Threonine (%)	0.89	0.87	0.76	0.74	0.78	0.80
Tryptophan (%)	0.29	0.28	0.31	0.30	0.27	0.27

** or eqivalent MHA*
*** with choline*

Table 3.4 Examples of pullet grower diets

	1	2	3	4	5	6
Corn	550	555				
Wheat			620	590		
Sorghum					568	558
Wheat shorts	150	165	150	160	150	150
Meat meal		50		20		20
Soybean meal	256	200	188	180	238	234
Fat	10	10.5	10	23.5	10	10
DL-Methionine*	1.2	1.3	1.3	1.3	1.7	1.6
Salt	3.3	2.7	2.7	2.5	3.4	3.2
Limestone	17.3	12.5	18	15.6	17.9	15.4
Dical Phosphate	11.2	2	9	6.1	10	6.8
Vit-Min Premix**	1	1	1	1	1	1
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	19.0	19.0	19.4	19.5	18.9	19.5
ME (kcal/kg)	2930	2930	2900	2930	2930	2930
Calcium (%)	0.97	0.97	0.97	0.97	0.97	0.97
Av. Phos. (%)	0.43	0.43	0.42	0.43	0.42	0.43
Sodium (%)	0.18	0.18	0.18	0.18	0.18	0.18
Methionine (%)	0.43	0.45	0.42	0.42	0.42	0.42
Meth + Cys. (%)	0.72	0.72	0.73	0.72	0.75	0.76
Lysine (%)	1.0	1.0	1.0	1.0	1.0	1.1
Threonine (%)	0.8	0.78	0.7	0.7	0.72	0.74
Tryptophan (%)	0.26	0.25	0.29	0.28	0.25	0.26

** or eqivalent MHA*

*** with choline*

Table 3.5 Examples of pullet developer diets

	1	2	3	4	5	6
Corn	534	535				
Wheat			648	649		
Sorghum					572	580
Wheat shorts	239	240	197	200	205	203
Meat meal		20		20		20
Soybean meal	186	167	114	96	181	161
Fat	10	10	10	10	10	10
DL-Methionine*	1.1	1.2	1.4	1.4	1.3	1.3
Salt	3.3	3.1	2.7	2.4	3.5	3.2
Limestone	16	16.4	17.5	15.4	17	15
Dical Phosphate	9.6	6.3	8.4	4.8	9.2	5.5
Vit-Min Premix**	1	1	1	1	1	1
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	16.5	16.5	16.5	16.5	16.5	16.5
ME (kcal/kg)	2855	2855	2850	2850	2850	2850
Calcium (%)	0.92	0.92	0.92	0.92	0.92	0.92
Av. Phos. (%)	0.39	0.39	0.39	0.39	0.39	0.39
Sodium (%)	0.18	0.18	0.18	0.18	0.18	0.18
Methionine (%)	0.39	0.39	0.38	0.38	0.35	0.35
Meth + Cys. (%)	0.63	0.63	0.63	0.63	0.64	0.64
Lysine (%)	0.82	0.83	0.79	0.79	0.86	0.86
Threonine (%)	0.69	0.68	0.57	0.56	0.62	0.61
Tryptophan (%)	0.22	0.22	0.24	0.24	0.22	0.21

** or eqivalent MHA*

*** with choline*

Table 3.6 Examples of prelay diets

	1	2	3	4	5	6
Corn	527	481				
Wheat			615	629		
Sorghum					574	593
Wheat shorts	227	306	180	180	180	180
Meat meal		50		34		60
Soybean meal	168	100	122	90	167	105
Fat	10	10	16.7	11	11	10
*DL-Methionine**	1.4	1.6	1.4	1.4	1.6	1.5
Salt	3	2.4	2.5	2	3.2	2.7
Limestone	51.6	46.6	51.5	48.2	51.3	46.8
Dical Phosphate	11	1.4	9.9	3.4	10.9	
*Vit-Min Premix***	1	1	1	1	1	1
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	16.0	16.0	16.6	17.0	16.0	16.2
ME (kcal/kg)	2850	2850	2850	2850	2850	2900
Calcium (%)	2.25	2.25	2.25	2.25	2.25	2.30
Av Phosphorus (%)	0.42	0.42	0.42	0.42	0.42	0.42
Sodium (%)	0.17	0.17	0.17	0.17	0.17	0.18
Methionine (%)	0.41	0.42	0.38	0.39	0.37	0.37
Meth + Cystine (%)	0.64	0.64	0.64	0.64	0.66	0.65
Lysine (%)	0.78	0.78	0.81	0.84	0.82	0.84
Threonine (%)	0.66	0.63	0.58	0.58	0.60	0.58
Tryptophan (%)	0.22	0.20	0.25	0.24	0.21	0.20

** or eqivalent MHA*
*** with choline*

3.2 Strain specific nutrient requirements

There are often questions about the need for strain-specific diets in growing white or brown egg pullets. Such differences would most likely be induced by differential growth rate and/or different mature body weight. As shown in Table 3.12 there are differences in growth rate of commercial pullets throughout the 18 week grow-out period. At 4 weeks of age, there is a 14% difference in body weight between the lightest and heaviest strain, while at 18 weeks this difference is 10%. This differential growth rate is reflected in nutrient needs, where for example, amino acid levels in the starter diet are 10-15% higher for this smaller strain.

Starter diets are shown in Table 3.7 where there is a fairly consistent energy base for all strains, although the diet for the smallest body weight strain, namely Lohmann, is much higher in lysine and threonine. This same trend continues for the grower diets (Table 3.8). Interestingly, for the developer diets (Table 3.9), the highest amino acid needs are for the heaviest pullet

Table 3.7 Starter diets for white egg pullets

Age fed (wks)	Shaver (0 to 6*)	Hyline 36 (0 to 6)	Hyline 98 (0 to 6)	Lohmann (0 to 3)	Bovan (0 to 6)
Protein (%)	19.5	20	20	21	20
ME (kcal/kg)	2900	2960	2960	2900	2980
Calcium (%)	1.0	1.0	1.0	1.05	1.0
Av. Phosphorus (%)	0.47	0.50	0.5	0.48	0.5
Sodium (%)	0.16	0.19	0.19	0.16	0.18
Linoleic acid (%)	1.2	1.0	1.0	1.4	1.3
Methionine (%)	0.42	0.48	0.48	0.48	0.45
Methionine+cystine (%)	0.73	0.8	0.8	0.83	0.8
Lysine (%)	0.95	1.1	1.1	1.2	1.1
Tryptophan (%)	0.20	0.20	0.20	0.23	0.21
Threonine (%)	0.68	0.75	0.75	0.8	0.75

** Extrapolated from Management Guide Information*

Table 3.8 Grower diets for white egg pullets

Age fed (weeks)	Shaver (6 to 12*)	Hyline 36 (6 to 8)	Hyline 98 (6 to 8)	Lohmann (3 to 8)	Bovan (6 to 10)
Protein (%)	17.5	18	18	19	18
ME (kcal/kg)	2800	3025	2960	2800	2970
Calcium (%)	0.95	1.0	1.0	1.03	1.0
Av Phosphorus (%)	0.47	0.47	0.48	0.46	0.48
Sodium (%)	0.16	0.18	0.18	0.16	0.17
Linoleic acid (%)	1.0	1.0	1.0	1.44	1.3
Methionine (%)	0.38	0.44	0.44	0.39	0.4
Methionine+cystine (%)	0.66	0.73	0.73	0.69	0.72
Lysine (%)	0.86	0.9	0.9	1.03	1.0
Tryptophan (%)	0.18	0.18	0.18	0.22	0.19
Threonine (%)	0.62	0.7	0.7	0.72	0.7

** Extrapolated from Management Guide Information*

Table 3.9 Developer diets for white egg pullets

	Shaver	Hyline 36	Hyline 98	Lohmann	Bovan
Age fed (weeks)	(12 to 17)	(8 to 15)	(8 to 16)	(8 to 16)	(10 to 15)
Protein (%)	16.5	16.0	16.0	14.9	16.0
ME (kcal/kg)	2750	3075	2940	2800	2960
Calcium (%)	1.15	1.0	1.0	0.92	1.0
Av Phosphorus (%)	0.45	0.45	0.46	0.38	0.45
Sodium (%)	0.16	0.17	0.17	0.16	0.17
Linoleic acid (%)	1.0	1.0	1.0	1.03	1.3
Methionine (%)	0.36	0.39	0.39	0.34	0.36
Methionine+cystine (%)	0.63	0.65	0.65	0.58	0.65
Lysine (%)	0.81	0.75	0.75	0.67	0.88
Tryptophan (%)	0.16	0.16	0.16	0.16	0.17
Threonine (%)	0.58	0.60	0.60	0.51	0.60

Table 3.10 Prelay diets for white egg pullets

	Hyline 36	Hyline 98	Lohmann	Bovan
Age fed (weeks)	(15 to 19*)	(16 to 18)	(16 to 18*)	(15 to 17)
Protein (%)	15.5	15.5	18	15
ME (kcal/kg)	3040	2940	2800	2930
Calcium (%)	2.75	2.75	2.05	2.25
Av Phosphorus (%)	0.4	0.45	0.46	0.45
Sodium (%)	0.18	0.18	0.16	0.18
Linoleic acid (%)	1.0	1.0	1.03	1.2
Methionine (%)	0.36	0.36	0.37	0.36
Methionine+cystine (%)	0.60	0.60	0.70	0.63
Lysine (%)	0.75	0.75	0.87	0.8
Tryptophan (%)	0.15	0.15	0.21	0.16
Threonine (%)	0.55	0.55	0.62	0.55

** Extrapolated from Management Guide Information*

Table 3.11 Feed intake for white egg pullets (grams)

	Shaver[1]	Hyline 36	Hyline 98	Lohmann	Bovan
Starter	1099	1085	1141	350	931
Grower	2072	621	665	1258	1239
Developer	2702	2645	3241	3327	2023
Pre-lay		860	980	1048	924
Layer		448			476
Total (to 18wks)	5873	5659	6027	5983	5593

[1] No prelay diet.

Table 3.12 Body weight of white egg pullets (grams)

Week	Shaver	Hyline 36	Hyline 98	Lohmann	Bovan
1	70	65	65	70	70
2	135	110	110	115	105
3	205	180	180	170	175
4	280	250	260	240	250
5	365	320	350	320	320
6	450	400	450	400	395
7	535	500	550	470	475
8	620	590	650	540	560
9	700	680	750	614	650
10	775	770	850	682	735
11	845	870	930	749	820
12	915	950	1000	816	900
13	975	1030	1070	878	975
14	1035	1100	1130	941	1045
15	1095	1160	1180	998	1110
16	1165	1210	1230	1056	1170
17	1235	1250	1270	1118	1225
18	1300	1280	1320	1181	1270

(Shaver) while the smaller Lohmann apparently need much lower amino acid intake. There is considerable variation in the specifications for strain-specific prelay diets (Table 3.10).

To some extent, variable diet specifications for prelay diets relate to age of bird. Prelay diets are most beneficial in terms of optimizing calcium accretion, and so it is somewhat surprising that there is a considerable range of calcium (2.05 to 2.75%) and available phosphorus (0.4 to 0.5%) given for the various strains. At this time, the Lohmann seems to have higher amino acid needs. The various strains of pullets consume anywhere from 5.6 to 6.0 kg of feed to 18 weeks, and this is somewhat influenced by diet energy level (Table 3.11).

Body weight of pullets are shown in Table 3.12.

There are significant differences in vitamin-mineral premixes suggested for the various strains of commercial pullets (Table 3.13). In some instances, the breeding companies do not give a specification for a certain nutrient, and presumably this means that the natural ingredients provide adequate levels for this strain of bird. For critical nutrients such as vitamin E there are six-fold differences in suggested specifications.

Comparable diet specifications for brown egg pullets are shown in Tables 3.14 to 3.20. There seems to be more consistency in strain specific specifications for brown egg pullets, although it should be emphasized that the feeding schedule in terms of bird age is more variable.

Table 3.13 Vitamin-mineral premix for white egg pullets

	units/kg feed	*Shaver*	*Hyline 36,98*	*Lohmann*	*Bovan*
Vitamin A	*IU*	*12000*	*8000*	*12000*	*8000*
Vitamin D_3	*IU*	*2500*	*3300*	*2000*	*2500*
Vitamin E	*IU*	*30*	*66*	*20**	*10*
Vitamin K	*IU*	*3*	*5.5*	*3*	*3*
Thiamin	*mg*	*2.5*	*0*	*1*	*1*
Riboflavin	*mg*	*7*	*4.4*	*4*	*5*
Pantothenic acid	*mg*	*12*	*5.5*	*8*	*7.5*
Niacin	*mg*	*40*	*28*	*30*	*30*
Pyridoxine	*mg*	*5*	*0*	*3*	*2*
Biotin	*µg*	*200*	*55*	*50*	*100*
Folic acid	*mg*	*1*	*0.22*	*1*	*0.5*
Vitamin B_{12}	*µg*	*30*	*8.8*	*15*	*12*
Choline	*mg*	*1000*	*275*	*200**	*300*
Iron	*mg*	*80*	*33*	*25*	*35*
Copper	*mg*	*10*	*4.4*	*5*	*7*
Manganese	*mg*	*66*	*66*	*100*	*70*
Zinc	*mg*	*70*	*66*	*60*	*70*
Iodine	*mg*	*0.4*	*0.9*	*0*	*1*
Selenium	*mg*	*0.3*	*0.3*	*0.2*	*0.25*

** Extrapolated from Management Guide Information*

Table 3.14 Starter diets for brown egg pullets

Age fed (weeks)	Shaver (0 to 4)	ISA (0 to 5)	Hyline (0 to 6)	Bovan (0 to 6)
Protein (%)	20.5	20.5	19.0	20.0
ME (kcal/kg)	2950	2950	2870	2980
Calcium (%)	1.07	1.07	1.0	1.0
Av Phosphorus (%)	0.48	0.48	0.48	0.5
Sodium (%)	0.16	0.16	0.18	0.18
Linoleic acid (%)			1.0	1.3
Methionine (%)	0.52	0.52	0.48	0.45
Methionine+cystine (%)	0.86	0.86	0.8	0.8
Lysine (%)	1.16	1.16	1.1	1.1
Tryptophan (%)	0.21	0.21	0.2	0.21
Threonine (%)	0.78	0.78	0.75	0.75

Table 3.15 Grower diets for brown egg pullets

Age fed (wks)	Shaver (4 to 10)	ISA (5 to 10)	Hyline (6 to 9)	Lohmann (0 to 8)	Bovan (6 to 10)
Protein (%)	19.0	20.0	16.0	18.5	18.0
ME (kcal/kg)	2850	2850	2890	2775	2940
Calcium (%)	1.0	1.0	1.0	1.0	1.0
Av Phosphorus (%)	0.42	0.44	0.46	0.45	0.5
Sodium (%)	0.16	0.17	0.18	0.16	0.17
Linoleic acid (%)			1	1.4	1.3
Methionine (%)	0.45	0.47	0.44	0.38	0.4
Methionine+cystine (%)	0.76	0.80	0.70	0.67	0.72
Lysine (%)	0.98	1.03	0.9	1.0	1.0
Tryptophan (%)	0.19	0.2	0.18	0.21	0.19
Threonine (%)	0.66	0.69	0.7	0.7	0.7

Table 3.16 Developer diets for brown egg pullets

	Shaver	ISA	Hyline	Lohmann	Bovan
Age fed (wks)	(10 to 16)	(10 to 16)	(9 to 16)	(8 to 16)	(10 to 15)
Protein (%)	16.0	16.8	15.0	14.5	15.5
ME (kcal/kg)	2750	2750	2830	2775	2840
Calcium (%)	0.95	1.0	1.0	0.9	1.0
Av Phosphorus (%)	0.36	0.38	0.44	0.37	0.45
Sodium (%)	0.16	0.17	0.16	0.16	0.17
Linoleic acid (%)			1.0	1.0	1.2
Methionine (%)	0.33	0.35	0.39	0.33	0.35
Methionine+cystine (%)	0.60	0.63	0.60	0.57	0.63
Lysine (%)	0.74	0.78	0.70	0.65	0.85
Tryptophan (%)	0.16	0.17	0.15	0.16	0.16
Threonine (%)	0.50	0.53	0.60	0.50	0.60

Table 3.17 Prelay diets for brown egg pullets

	Shaver	ISA	Hyline	Lohmann	Bovan
Age fed (wks)	(16 to 17)	(16 to 17*)	(16 to 18*)	(16 to 18*)	(15 to 17)
Protein (%)	17.0	17.0	16.5	17.5	14.8
ME (kcal/kg)	2750	2750	2850	2775	2820
Calcium (%)	2.05	2.05	2.75	2.0	2.25
Av Phosphorus (%)	0.45	0.45	0.44	0.45	0.45
Sodium (%)	0.16	0.16	0.18	0.16	0.18
Linoleic acid (%)			1.0	1.0	1.2
Methionine (%)	0.36	0.36	0.35	0.36	0.35
Methionine+cystine (%)	0.65	0.65	0.60	0.68	0.63
Lysine (%)	0.80	0.80	0.75	0.85	0.80
Tryptophan (%)	0.17	0.17	0.17	0.20	0.16
Threonine (%)	0.54	0.54	0.55	0.60	0.55

** Extrapolated from Management Guide Information*

All poultry breeding companies recommend prelay diets for their brown egg pullets, and while most nutrient specifications are similar, there are again major differences in recommendations for calcium. These brown egg pullets weigh from 1475g to 1580g at 18 weeks, and consume anywhere from 6.3 to 6.8 kg feed (Tables 3.18 and 3.19). As for the white egg pullets, the strain specifications for vitamin-mineral premixes for the brown pullets show tremendous variation, and again for some strains, certain nutrients are not deemed essential within these premixes (Table 3.20).

Table 3.18 Feed intake[1] for brown egg pullets (grams)

	Shaver	*ISA*	*Hyline*	*Lohmann*	*Bovan*
Starter	600	840	1099		1148
Grower	2100	1694	966	1764	1351
Developer	3000	2758	3346	3577	2170
Pre-lay	588	525	1163	1029	1015
Layer	600	480			539
Total (to 18 wks)	6888	6297	6574	6370	6223

[1]*Dependent on diet energy level*

Table 3.19 Body weight of brown egg pullets (grams)

Week	*Shaver*	*ISA*	*Hyline*	*Lohmann*	*Bovan*
1	60	50	70	75	70*
2	100	100	115	130	110*
3	200	190	190	195	180*
4	300	280	280	275	290
5	380	380	380	367	370
6	480	480	480	475	450
7	570	580	580	580	530
8	650	675	680	680	610
9	760	770	770	780	690
10	850	850	870	875	770
11	940	950	960	960	850
12	1030	1040	1050	1040	935
13	1120	1130	1130	1120	1020
14	1220	1220	1210	1200	1110
15	1320	1300	1290	1265	1200
16	1400	1390	1360	1330	1300
17	1490	1475	1430	1400	1400
18	1580	1560	1500	1475	1500

* *Extrapolated from Management Guide Information*

Table 3.20 Vitamin-mineral premix for brown egg pullets

	units/kg feed	Shaver	ISA	Hyline	Lohmann	Bovan
Vitamin A	IU	13000	13000	8800	12000	8000
Vitamin D_3	IU	3000	3000	3300	2000	2500
Vitamin E	IU	25	25	66	10-30	10
Vitamin K	IU	2	2	5.5	3	3
Thiamin	mg	2	2	0	1	1
Riboflavin	mg	5	5	4.4	6	5
Pantothenic acid	mg	15	15	5.5	8	7.5
Niacin	mg	60	60	28	30	30
Pyridoxine	mg	5	5	0	3	2
Biotin	µg	200	200	55	50	100
Folic acid	mg	0.75	0.75	0.22	1.0	0.5
Vitamin B_{12}	µg	20	20	8.8	15.0	12
Choline	mg	600	600	275	300	300
Iron	mg	60	60	33	25	35
Copper	mg	5	5	4.4	5	7
Manganese	mg	60	60	66	100	70
Zinc	mg	60	60	66	60	70
Iodine	mg	1	1	0.9	0.5	1
Selenium	mg	0.2	0.2	0.3	0.2	0.25

3.3 Feeding management of growing pullets

a) General considerations

Diet formulation and feeding management are now critical aspects of growing pullets to the onset of sexual maturity. Age at maturity is getting earlier although it is questionable that this has changed suddenly in just a few years. In fact, what has been happening is that age at maturity has slowly been decreasing by almost 1 d per year, and this is especially true for many strains of brown egg pullets. Moving birds to laying cages at 19-20 weeks is no longer feasible and often results in management problems. Similarly, first egg appearing at 15-17 weeks means that we must critically review our rearing programs. The key to successful nutritional management today is through optimizing (maximizing) body weight of the pullet. Pullets that are on-target or slightly above target weight at maturity will inevitably be the best producing birds for the shell egg market.

The traditional concern with early maturity has been too small an egg size. Results from our early studies indicate the somewhat classical

Table 3.21 Pullet maturity and egg characteristics

Age at Lighting (wk)	*Egg production (%)*		*Egg size (% large)*	
	18-20 wk	*Mean (to 35 wk)*	*30 wk*	*63 wk*
15	32	92	17	44
18	12	92	21	65
21	0	91	37	69

effect of early maturity in Leghorns without regard to body weight (Table 3.21).

There seems little doubt that body weight and perhaps body composition at this time are the major factors influencing egg size both at maturity and throughout the remainder of the laying period. Summers and Leeson (1983) concluded that body weight is the main factor controlling early egg size (Table 3.22).

Table 3.22 Effect of body weight on egg size

18 wk wt (g)	*Early egg wt (g)*
1100	46.9
1200	48.4
1280	48.8
1380	49.7

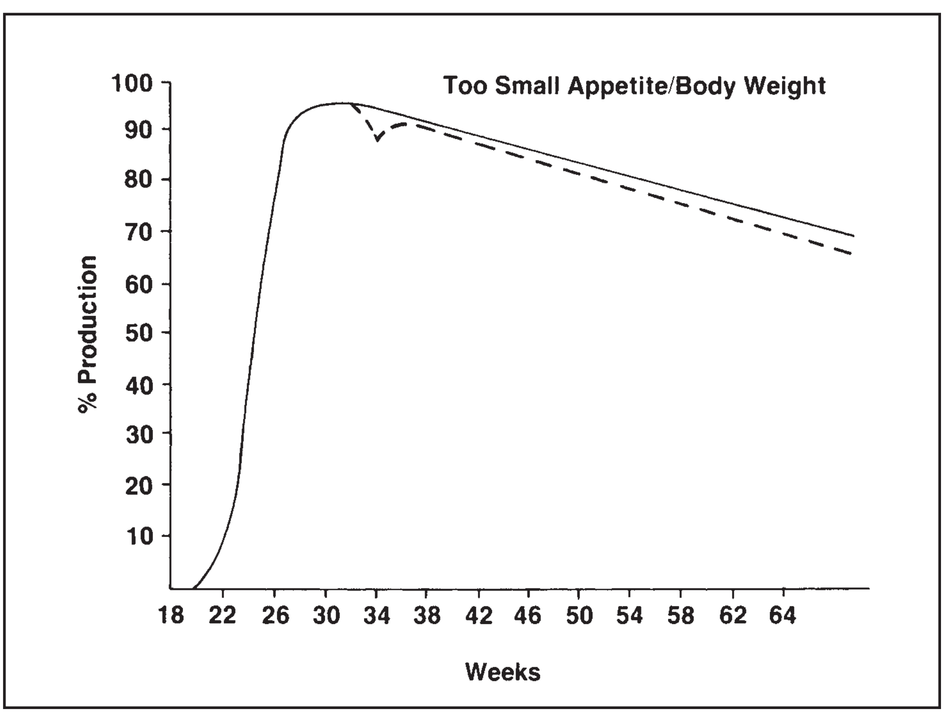
Although there is some evidence to indicate that nutrients such as protein, methionine and linoleic acid can influence egg size throughout the laying cycle, these nutrients have only moderate effects on early egg size. This is probably related to the pullet producing at maximum capacity at least up to the time of peak egg mass.

Although it is fairly well-established that body weight is an important criterion for adequate early production, there is still insufficient evidence regarding optimum body structure and composition. Frame size is still discussed, although standards are now rarely given in the breeder management guides. It is known that most (90%) of the frame size is developed early, and so by 12-16 weeks of age, the so-called 'size' of the pullet is fixed. While this parameter is useful as another monitoring tool, we have had little success in affecting frame size without also affecting body weight. It therefore seems very difficult to produce, by nutritional modification, pullets that are below target weight, yet above average frame size and vice versa. Since shank length and 'frame size' are so highly correlated with body weight, their measurement or monitoring is no longer considered necessary. However, an exception to this rule occurs in hot weather conditions where high temperatures seem to stimulate leg bone growth independent of body weight. It is not clear why birds held at higher temperatures have longer shank bones, although there is a possibility of altered hormone balance. For example, thyroid hormones are known to influence bone development through mediation of somatomedins and it has been shown that even though birds held at 30 vs. 22ºC have reduced thyroid size, their circulating T4 levels are increased by 100%. Another factor that may be of importance is blood flow to the feet and legs during heat stress. It is well known that birds divert more blood to the legs during heat stress as a means of countercurrent cooling between the arterial and venous supply. In some types of birds, heat loss from the legs can be the largest contributor to overall heat loss, and it is interesting that this has been recorded to occur at 30ºC since

at higher tempertures evaporative losses become more important. Since the hind limbs are apparently more heavily supplied with blood at 30 vs. 18ºC, and even though nutrient intake is reduced at higher temperatures, it is conceivable that the active growth plate receives a greater supply of nutrients related simply to increased blood flow. It would be interesting to see if environmental temperature influences development of other parts of the skeleton and especially the keel.

While pullets are maturing earlier, there has been little change in body weight at time of first egg. As will be discussed in section 3.3g), lighting program is the most important stimulus to maturity. Pullets as young as 8 weeks of age will be influenced by light stimulation, and regardless of body weight or composition, will produce eggs earlier than normal. Without any light stimulation, then a minimum threshold body weight and/or body composition is most likely the stimulus to maturity. There may, in fact, be a need for attainment of a minimum lean body mass prior to sexual maturation. With most mammals, attainment of minimum fat reserves are essential for puberty, and so it seems likely that body composition is as important as total body mass in influencing the onset of egg production. In studies involving a relatively small number of birds, we have seen no correlation between age at first egg and either percentage or absolute levels of body fat. While no clear picture has yet emerged with respect to body composition and maturity, it seems likely that birds having some energy reserve, as they approach peak egg production, are less prone to subsequent production problems. A production curve as shown in Figure 3.1 is often observed in flocks, related to inadequate body size or energy reserves at the time of maturity.

Fig. 3.1 Reduction in egg production after peak, associated with small appetite and body weight.



When this type of production loss is not due to an identifiable disease and/or management problem, then it most likely relates to birds being deficient in energy. It is perhaps not too surprising that birds are in such a precarious situation with respect to energy balance. Dairy cows and sows invariably lose body weight during peak lactation in order to meet energy requirements. Perhaps the most classical case of energy deficiency at this time is seen with the turkey breeder. Due to a decline in feed intake from time of first lighting through to peak egg production, the turkey breeder necessarily loses considerable body mass in an attempt to maintain energy balance. It is likely that the same situation applies to Leghorn pullets and in some cases, to brown egg birds. Obviously, the effect is most pronounced for underweight flocks with small appetites where energy intake is minimal. In fact, with many flocks exhibiting production characteristics as shown in Figure 3.1, it is body weight at housing that deserves immediate investigation rather than factors occurring at the actual time of the production loss.

The key to optimizing layer performance would seem to be attainment of body weight goals at time of maturity. It is likely that body condition will be a factor of the flock in question, being influenced by stocking density, environmental temperature, feather cover, etc. Unfortunately attainment of desired weight for age is not always easy to achieve especially where earlier maturity is desired or when adverse environmental conditions prevail. Leeson and Summers (1981) suggested that energy intake of the pullet is the limiting factor to growth rate, since regardless of diet specifications, pullets seem to consume similar quantities of energy (Table 3.23). In this study, all pullets had a similar body weight at 15 weeks even though diet specifications were dramatically variable. As seen in Table 3.23, birds consumed similar quantitities of energy even though protein intake varied by 85%. These data suggest that if protein and amino acid intake are adequate, additional diet protein does little to stimulate growth rate.

In other studies, we have reared Leghorn pullets on diets varying in protein or energy, and again, energy intake seems to be the major factor influencing body weight (Tables 3.24 and 3.25). These studies indicate that growth rate is more highly correlated with energy intake than with protein intake. This does not mean to say that protein (amino acid) intake is not important to the growing pullet. Protein intake is very important, but there does not seem to be any measurable return from feeding more than 800 g of protein to the pullet through 18 weeks of age. On the other hand, it seems as though the more energy consumed by the pullet, the larger the body weight at maturity. Obviously, there must be a fine line between maximizing energy intake and creating an obese pullet.

Table 3.23 Nutrient intake of pullets (8-15 weeks)

Diet energy-protein	*15 wk Body wt. (g)*	*Energy intake (Mcal)*	*Protein intake (g)*
2950 kcal – 15% CP	*1272*	*9.77*	*464[c]*
3100 kcal – 24% CP	*1267*	*9.17*	*718[a]*
3200 kcal – 20% CP	*1291*	*9.51*	*597[b]*

Table 3.24 Effect of diet protein level (0-20 wks) on pullet growth and nutrient intake

Diet Protein (%)	*Body wt. (g)*	*Energy intake (Mcal)*	*Protein intake (kg)*
15	1445	24.3	1.28[d]
16	1459	22.9	1.28[d]
17	1423	22.9	1.37[cd]
18	1427	22.0	1.39[c]
19	1444	22.9	1.53[b]
20	1480	23.0	1.62[a]

All diets 2850 kcal ME/kg

Table 3.25 Effect of diet energy level (0-20 wks) on pullet growth and nutrient intake

Diet energy (kcal ME/kg)	*Body wt. (g)*	*Energy intake (Mcal)*	*Protein intake (kg)*
2650	1320[c]	20.6[c]	1.40[a]
2750	1378[bc]	21.0[bc]	1.37[a]
2850	1422[ab]	21.8[ab]	1.37[a]
2950	1489[a]	22.1[ab]	1.35[ab]
3050	1468[a]	21.4[abc]	1.26[c]
3150	1468[a]	22.5[a]	1.29[bc]

All diets:18% CP, 0.36% methionine [a]and 0.9% lysine

b) Manipulating nutrient intake

If one calculates expected energy output in terms of egg mass and increase in body weight, and relates this to feed intake, then it becomes readily apparent that the Leghorn must consume at least 90 g/bird/day and the brown egg bird close to 100 g/bird/day at peak production. Because feeding is *ad-libitum*, management programs must be geared at stimulating early appetite. The practical long-term solution is to rear birds with optimum body weight and body reserves at maturity. This situation has been aggravated in recent years, with the industry trend of attempting to rear pullets on minimal quantitites of feed. Unfortunately, this move has coincided with genetically smaller body weights and hence smaller appetites, together with earlier sexual maturity.

In order to maximize nutrient intake, one must consider relatively high nutrient dense diets, although these alone do not always ensure optimum growth. Relatively high protein (16-18% CP) with adequate methionine (2% CP) and lysine (5% CP) levels together with high energy levels (2800-3000 kcal/kg) are usually given to Leghorn pullets, especially in hot weather situations. However, there is some evidence to suggest that high energy diets are not always helpful under such warm conditions. (Table 3.26)

Leghorn pullets were heavier at 126 d when fed the high energy diet in the cool environment, but diet had no effect at 30ºC. As expected, pullets ate less of the high energy diet, and because

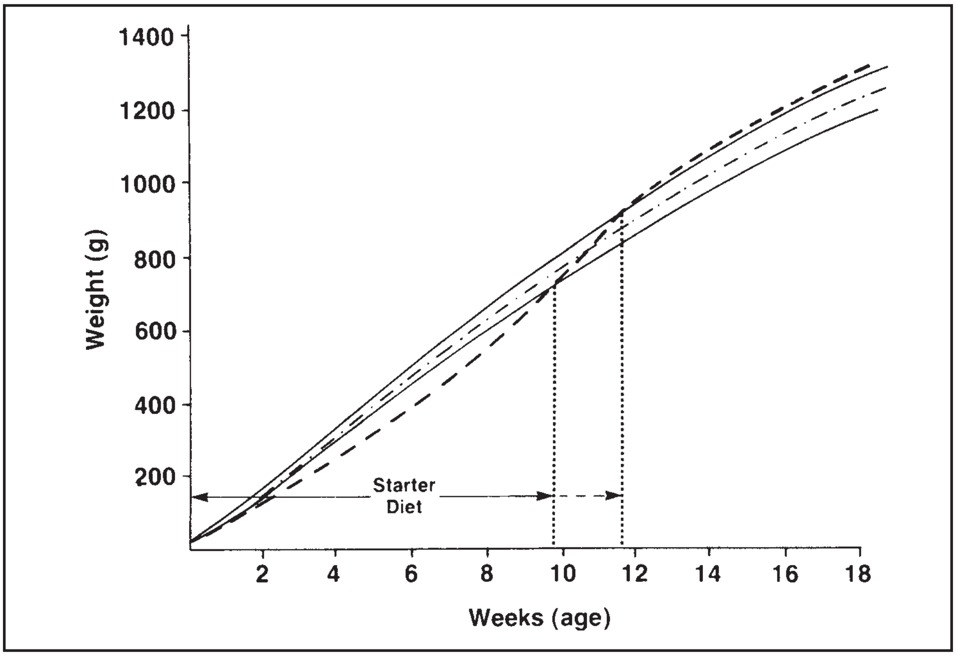
Table 3.26 Influence of diet energy on growth and nutrient intake of leghorn pullets maintained at 30 or 18°C to 18 weeks of age

	Body wt 126 d (g)	Total feed intake (kg)	ME intake (Mcal)	Protein intake (g)
Temperature 18ºC				
2500 kcal ME/kg	1398	7.99	20.04	1330
3000 kcal ME/kg	1434	6.98	21.07	1160
Temperature 30ºC				
2500 kcal ME/kg	1266	6.05	15.17	1010
3000 kcal ME/kg	1218	5.19	15.69	870

all other nutrient levels were fixed, this resulted in reduced intake of all nutrients except energy. Pullets therefore ate less protein and amino acids when fed 3000 vs. 2500 kcal ME/kg, and this can be critical where intake *per se* is less at 30ºC. The pullets fed 3000 kcal/kg are borderline in intake of balanced protein at 870 g vs. our requirement for 800 g to this age. High energy diets may therefore not always be beneficial under heat stress conditions, and intake of other nutrients such as protein and amino acids must be given priority during formulation. The Leghorn pullet eats for energy requirement, albeit with some imprecision, and so energy:protein balance is critical. All too often there is inadequate amino acid intake when high energy corn-based diets are used, the result of which is pullets that are both small and fat at maturity.

One of the most important concepts today in pullet feeding, is to schedule diets according to body weight and condition of the flock, rather than according to age. For example, traditional systems involve feeding starter diets for about 6 weeks followed by grower and then developer diets. This approach does not take into account individual flock variation, and this will be inappropriate for underweight flocks. It is becoming more difficult to attain early weight for age. This means that flocks are often underweight relative to management guide values (Table 3.12) at 4-6 weeks of age. This situation can arise for a variety of reasons such as sub-optimal nutrition, heat stress, disease, etc. For such flocks it is inappropriate to change from starter to grower diet, merely because the flock has reached some arbitrary age. It is more appropriate to feed the higher nutrient dense starter until the target weight is reached. For example, Figure 3.2 shows an underweight flock at 6 weeks. For this flock to receive a grower at 6 weeks of age will cause problems because the flock will likely stay small until maturity, be late maturing, and then produce a sub-optimal number of eggs that will also be small. This type of flock can most effectively be 'corrected' in growth by prolonged feeding of the starter diet. In this situation, the birds reach the low end of the guide weight at almost 10 weeks of age (Figure 3.2). At this time, a grower diet could be introduced. Since the flock is showing a growth spurt, then feeding to almost 12 weeks could be economical. The flock is now slightly over-weight and so ideally suited to realizing maximum genetic potential during peak production. Some producers, and especially contract pullet growers, are sometimes reluctant to accept this type of program, since they correctly argue that feeding a high protein starter diet for 10-12 weeks will be more expensive. Depending upon local economic conditions,

Fig. 3.2 Pullet growth in relation to feeding program.



feeding an 18% protein starter diet for 12 vs. 6 weeks of age, will cost the equivalent of 2 eggs. A bird in ideal condition at maturity will produce far in excess of these 2 eggs relative to a bird that is underweight at maturity.

c) Suggested feeding program

Diet specification, together with approximate ages for feeding, are given in Tables 3.1 and 3.2 for Leghorns and brown egg birds respectively. In practice, flocks may not grow according to expected standards, and for Leghorns at least, they are more likely to be underweight than on target. Brown egg strains on the other hand, because of their inherently higher feed intake, sometimes achieve weights that are greater than standard goals. For these reasons, there needs to be flexibility in time of change from, for example, starter to grower etc. Table 3.27 shows various scenarios for the feeding scheduling of a Leghorn strain to 17 weeks of age. According to the standard schedule, the starter and grower are each fed for 6 weeks, followed by developer. In Scenario #1, the body weight is below standard at 3 weeks, and pullets are only 400 g at 6 weeks relative to the standard of 450 g at this time. If this flock is changed to the lower nutrient dense grower diet at 6 weeks, the birds will not likely achieve target weight at maturity. For this reason in Scenario #1, the starter diet is continued until weight-for-age is achieved at 9 weeks of age. In Scenario #2 there is even greater cause for concern since the flock suddenly slows down in growth at 9 weeks of age. This type of growth depression is seen in situations of disease challenge, with severe beak trimming or when there is sudden increase in environmental temperature. For this flock, it is essential to re-introduce the higher nutrient dense starter diet in order to stimulate growth. In this extreme situation, the grower diet is introduced at 12 weeks since the pullets seem to be making acceptable weekly gains in growth.

However, grower is fed for two weeks longer than normal, during weeks 13 and 14, to ensure ideal weight at 17 weeks.

Table 3.28 shows examples for feed scheduling of brown egg birds where increased growth is the problem. In Scenarios 1 and 2, the pullets are overweight at various ages according to the standard. In Scenario #1, pullets are overweight at 5 weeks and so the lower nutrient dense grower diet is introduced a week early. Likewise developer diet type is used from 10 rather than 11 weeks. In Scenario #2, pullet growth is much higher than standard. This growth is tempered somewhat by earlier introduction of grower and developer diets, yet pullets are still overweight at 16 weeks. Because such rapid growth will result in earlier maturity it may be advisable to light stimulate this flock a week earlier than scheduled, with appropriate early introduction of the layer diet.

The examples shown in Table 3.27 and Table 3.28 emphasize the need for flexibility in feed scheduling. For most flocks, the end goal will likely be the breeder's recommended target weight at 16-18 weeks or whenever light stimulation occurs. In certain situations it may be necessary to manipulate mature body weight according to economics of manipulating egg size and egg grade (see Section d). As a generalization, the smaller the body weight of the pullet, the smaller the size of the egg throughout the entire laying cycle. Conversely, a larger pullet will always produce a bigger egg and this is little influenced by layer nutrition.

Table 3.27 Feeding scenarios for White pullets according to growth (g)

	Standard		*Scenario #1*		*Scenario #2*	
Week(s)	*Body wt.*	*Feed type*	*Body wt.*	*Feed type*	*Body wt.*	*Feed type*
1	*70*	*Starter*	*70*	*Starter*	*70*	*Starter*
2	*135*	*Starter*	*130*	*Starter*	*135*	*Starter*
3	*205*	*Starter*	*190*	*Starter*	*205*	*Starter*
4	*280*	*Starter*	*255*	*Starter*	*280*	*Starter*
5	*365*	*Starter*	*320*	*Starter*	*365*	*Starter*
6	*450*	*Starter*	*400*	*Starter*	*450*	*Starter*
7	*535*	*Grower*	*500*	*Starter**	*535*	*Grower*
8	*620*	*Grower*	*600*	*Starter**	*620*	*Grower*
9	*700*	*Grower*	*700*	*Starter**	*650*	*Starter**
10	*775*	*Grower*	*775*	*Grower*	*720*	*Starter**
11	*845*	*Grower*	*845*	*Grower*	*800*	*Starter**
12	*915*	*Grower*	*915*	*Grower*	*870*	*Grower*
13	*975*	*Developer*	*975*	*Developer*	*950*	*Grower**
14	*1035*	*Developer*	*1035*	*Developer*	*1000*	*Grower**
15	*1095*	*Developer*	*1095*	*Developer*	*1095*	*Developer*
16	*1165*	*Developer*	*1165*	*Developer*	*1165*	*Developer*
17	*1235*	*Developer*	*1235*	*Developer*	*1235*	*Developer*

** different from standard*

Table 3.28 Feeding scenarios for ISA Brown pullets according to growth (g)

Week(s)	Standard		Scenario #1		Scenario #2	
	Body wt.	Feed type	Body wt.	Feed type	Body wt.	Feed type
1	50	Starter	50	Starter	50	Starter
2	100	Starter	110	Starter	110	Starter
3	190	Starter	200	Starter	210	Starter
4	280	Starter	290	Starter	320	Grower*
5	380	Starter	420	Grower*	460	Grower*
6	480	Grower	510	Grower	550	Grower
7	580	Grower	600	Grower	650	Grower
8	675	Grower	700	Grower	780	Developer*
9	770	Grower	790	Grower	900	Developer*
10	850	Grower	870	Developer*	980	Developer*
11	950	Developer	960	Developer	1050	Developer
12	1040	Developer	1040	Developer	1200	Developer
13	1130	Developer	1130	Developer	1260	Developer
14	1220	Developer	1220	Developer	1320	Developer
15	1300	Developer	1300	Developer	1350	Developer
16	1390	Developer	1390	Developer	1430	Layer*

** different from standard*

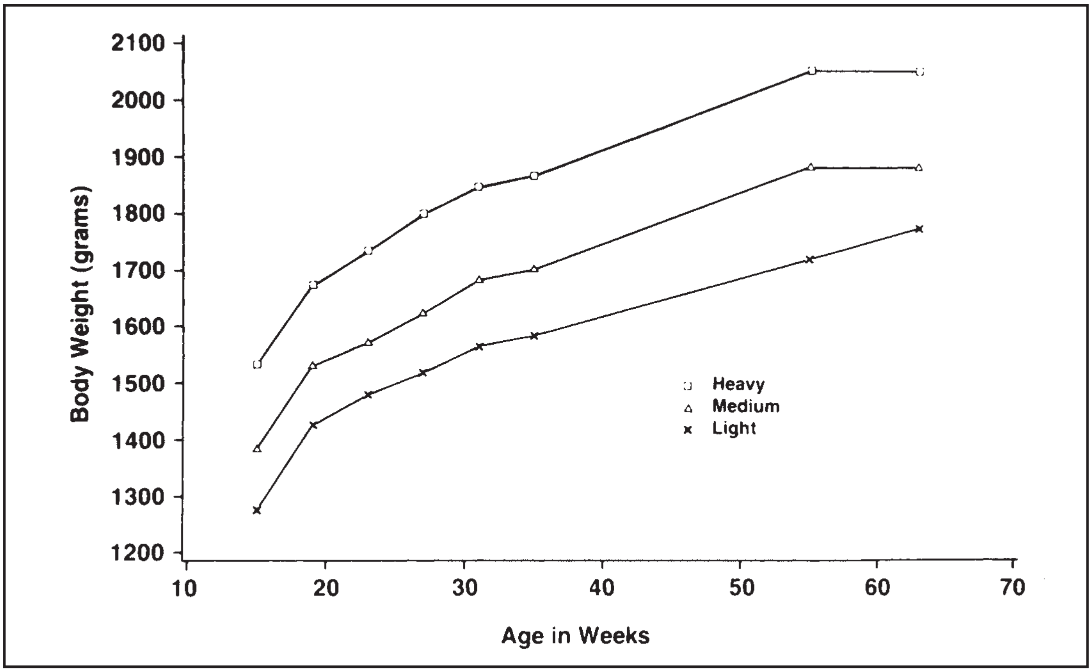
Table 3.29 Effect of immature body weight on development to sexual maturity

Body weight (g)			Age at first egg (d)	Weight of first egg (g)
18 wks	1st egg	Change		
1100	1360	+260	153	40.7
1200	1440	+240	150	42.0
1280	1500	+220	149	43.7
1380	1590	+210	148	42.5

An argument that is often heard about the role of body weight at maturity, is that it is not in fact, too important because the pullet will show catch-up growth prior to first egg. In other words, if the pullet is small, it will take a few days longer to mature, and start production at the 'same weight'. However, this does not seem to happen, as small birds at 18 weeks are smaller at time of laying their first egg (Table 3.29).

For the smaller pullet there is a degree of compensatory growth up to the time of the first egg, although this is insufficient to allow for total 'catch-up' growth. It is also interesting to note the relationship between body weight and age at first egg and also between body weight and size of first egg. In other studies, we have monitored the growth of pullets through a production cycle in relation to 18 week body weight which is the age of light stimulation. Again, there is a remarkably

Fig. 3.3 Effect of immature body weight on subsequent body weight during lay.



similar pattern of growth for all weight groups indicating that immature weight seems to 'set' the weight of the bird throughout lay (Figure 3.3).

More importantly from a production viewpoint, is the performance of birds shown in Figure 3.3. When the lightest weight birds were fed diets of very high nutrient density (20% CP, 3000 kcal ME/kg) they failed to match egg production and egg size of the largest weight pullets that were fed very low nutrient dense diets (14% CP, 2600 kcal ME/kg). These results emphasize the importance of mature body weight in attaining maximum egg mass output.

The actual body weight achieved will obviously vary with strain and bird type (Tables 3.12, 3.19). For Leghorns, weight should be around 400-450 g at 6 weeks, 850-1000 g at 12 weeks and 1200-1300 g at 18 weeks. The brown egg strains will be 450-480 g at 6 weeks, 1000 g at 12 weeks and 1500-1600 g at 18 weeks. The brown egg strains will likely mature 7-10 d earlier than the Leghorn strains.

d) Manipulation of body weight at sexual maturity

In the previous section, the main emphasis was on attaining the breeder's recommended weight at time of sexual maturity. Under certain conditions, some tempering of mature body size may be economically advantageous. Because body size has a dramatic effect on egg size, large birds at maturity can be expected to produce large eggs throughout their laying cycle. Depending upon the pricing of various egg grades, a very large egg may be uneconomical to produce, and in most instances tempering of egg size of birds from 40-65 weeks of age is often difficult to do without associated loss in egg numbers. Because body weight controls feed intake and egg size, an easier way of manipulating life-cycle egg size is through the manipulation of mature body size.

If the maximum possible egg size is desired, then efforts must be made to realize the largest possible mature weight. However, where a smaller overall egg size is economical then a smaller pullet is desirable. Such lightweight pullets can be obtained by growing pullets more slowly or most easily by light-stimulating pullets at an earlier age. Figure 3.4 gives a schematic representation of the above concept. In this scenario, birds are on the heavy side of the breeder's weight guide, and so if moved at 18 weeks, would be heavier than the ideal weight and be expected to produce very large eggs. If this situation is not economical in the laying house, then these birds should be moved at the 'ideal weight' which in this scenario means moving at 17 rather than 18 weeks of age. Moving the bird, and light stimulating at 17 vs. 18 weeks will have no adverse effect on performance, as light stimulation is still at the desired body weight standard (that has been achieved one week earlier than anticipated).

Early maturity is not a problem for flocks that have ideal body weight and condition. Early maturity and light stimulation will only result in subsequent small egg size and increased incidence of prolapse if the bird is small at this age. This concept is preferred over attempts at trying to slow the bird down during growth in an attempt to delay maturity (Figure 3.5).

Fig. 3.4 Light stimulation at target weight rather than age.

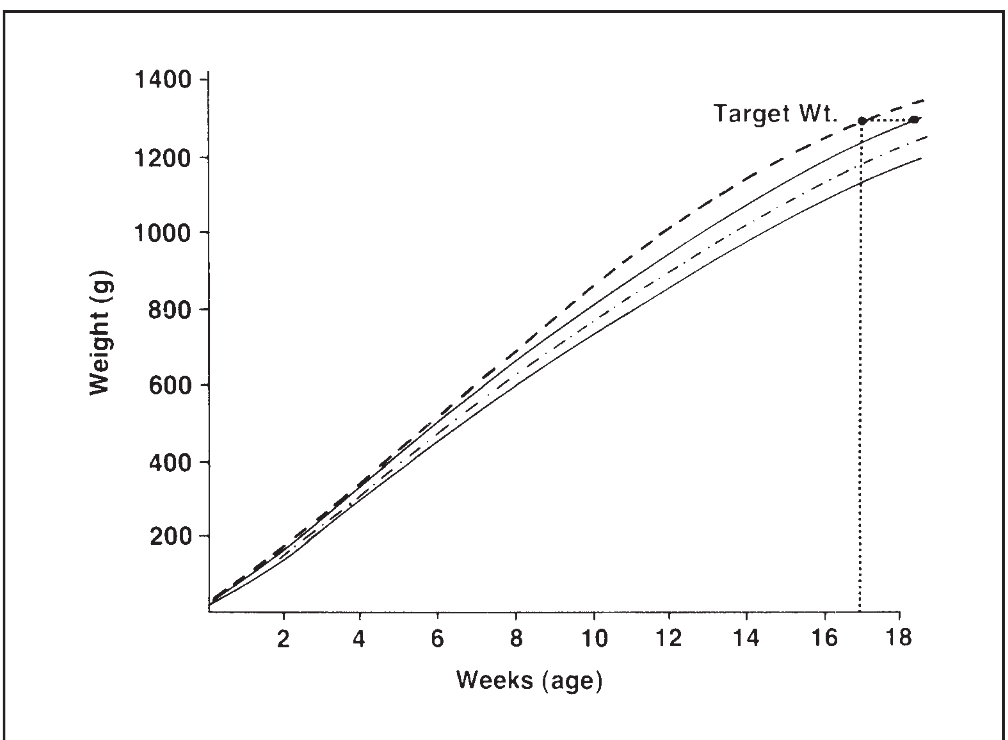
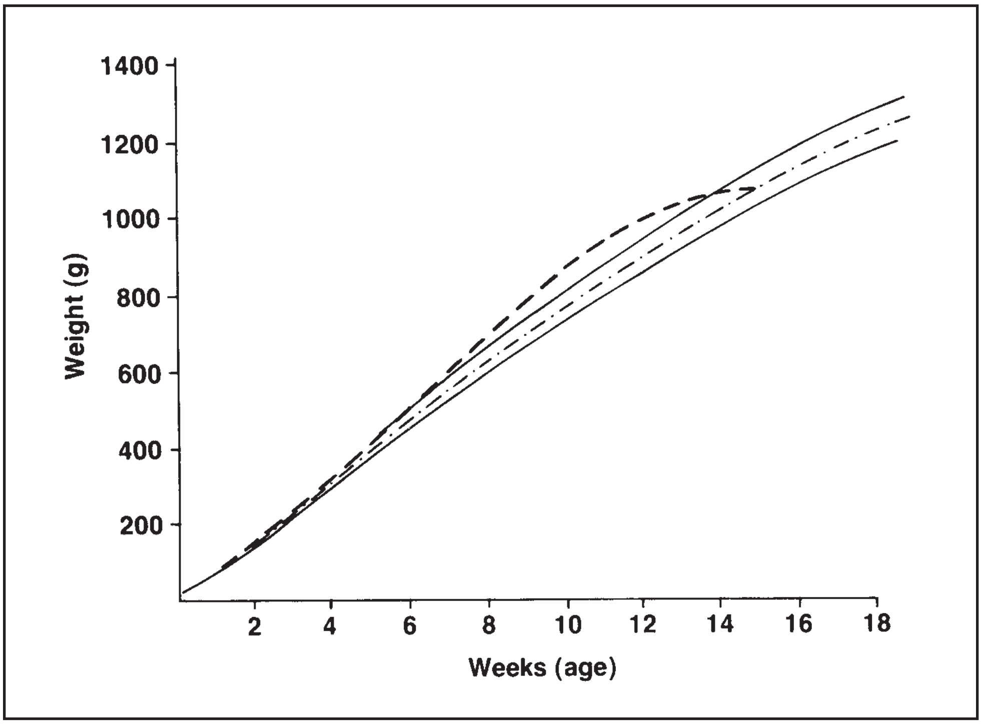


Fig. 3.5 Potentially harmful adjustment to pullet weight.



Such adjustments are invariably brought about by use of very low nutrient dense diets and/or use of restricted feeding. Both of these practices have the desired 'effect' of slowing down mean growth, but at the great cost of loss of pullet uniformity.

e) Nutrient management

Although growing pullets do not produce large quantities of manure in relation to adult layers, nutrient loading of manure will likely be a management consideration. Under average conditions of feeding and management, pullets will retain about 25% of nitrogen and 20% of phosphorus consumed. Most of the remaining phosphorus will be retained in the manure while around 30% of the excreted nitrogen will be lost as ammonia, either in the pullet house or during storage prior to land disposal. Based on these values for nutrient balance, Table 3.30 provides information on nutrient flow for pullets through to 18 weeks. On a per pullet basis therefore, each bird produces about 0.1 kg N and 0.03 kg P in the manure to 18 weeks of age.

Manure nutrient loading is in direct proportion to corresponding diet nutrient levels. Using lower protein or lower phosphorus diets will invariably result in less of these elements appearing in the manure. Attempts at reducing crude protein levels in pullet diets, as a means of reducing feed cost and/or manure N loading, often results in poor growth rate (Table 3.31). Regardless of constant levels of the most important amino acids in these diets, pullets responded adversely to any reduction in crude protein. This data suggests that pullets have minimal needs for non-essential amino acids and/or that requirements for amino acids such as threonine and arginine are of more importance than normally

Table 3.30 Nitrogen and phosphorus balance for 50,000 pullets to 18 weeks of age

	Intake (kg)[1]	Body retention (kg)	Excretion (kg)	Gas Loss (kg)	Manure (kg)
Nitrogen	7680	1920	5760	1760	5000
Phosphorus	1950	390	1560	-	1560

[1]Assumes 6 kg feed per pullet, averaging 16% CP (2.56% N) and 0.65% total phosphorus

Table 3.31 Body weight of Leghorn and brown egg pullets fed low protein diets with constant levels of TSAA, lysine and tryptophan

Diet CP (%)		Brown bird weight (g)			Leghorn weight (g)		
Starter[1]	Grower[2]	56d	98d	126d	56d	98d	126d
20	16	746[a]	1327[a]	1524[a]	592[a]	1086[a]	1291[a]
18	14	720[b]	1272[b]	1471[b]	576[b]	1046[b]	1235[b]
16	12	706[b]	1144[c]	1301[c]	546[c]	921[c]	1085[c]
14	10	540[c]	989[d]	1175[d]	434[d]	781[d]	932[d]

[1] 0.66% TSAA: 0.90% lysine; 0.24% tryptophan
[2] 0.55% TSAA; 0.72% lysine; 0.19% tryptophan

Table 3.32 Effect of dietary phosphorus on pullet development and phophorus excretion

Diet available P (%)			Body weight (g)		Feed intake (kg)	Tibia ash (%)	Manure P (kg/1000)
Starter	Grower	Developer	6 wk	18 wk			
0.40	0.35	0.30	345	1210	5.94	50.7	28
0.30	0.25	0.20	340	1260	5.98	49.3	24
0.20	0.15	0.10	330	1200	5.85	48.8	18

Adapted form Keshavarz (2000)

estimated. Regardless of mode of action, it seems that there is only limited potential to reduce the crude protein levels in pullet diets as a means of reducing manure nitrogen loading. There does seem to be potential for reducing diet phosphorus levels in pullet diets, to limit manure loading. Keshavarz (2000) shows acceptable pullet growth with diet levels as low as 0.2% in the starter diet (Table 3.32). There was an indication of slightly lower egg production to 30 weeks of age in pullets fed the lowest level of diet P, although growth characteristics were little affected. The P loading of manure of 28 kg/1000 agrees well with the prediction shown in Table 3.30. It seems as though there is potential for at least 30% reduction in manure P output of pullets through diet formulation.

f) Prelay nutrition and management

i) Considerations for calcium metabolism – Prelay diets and prelay management are designed to allow the bird the opportunity to establish adequate medullary bone reserves that are neces-

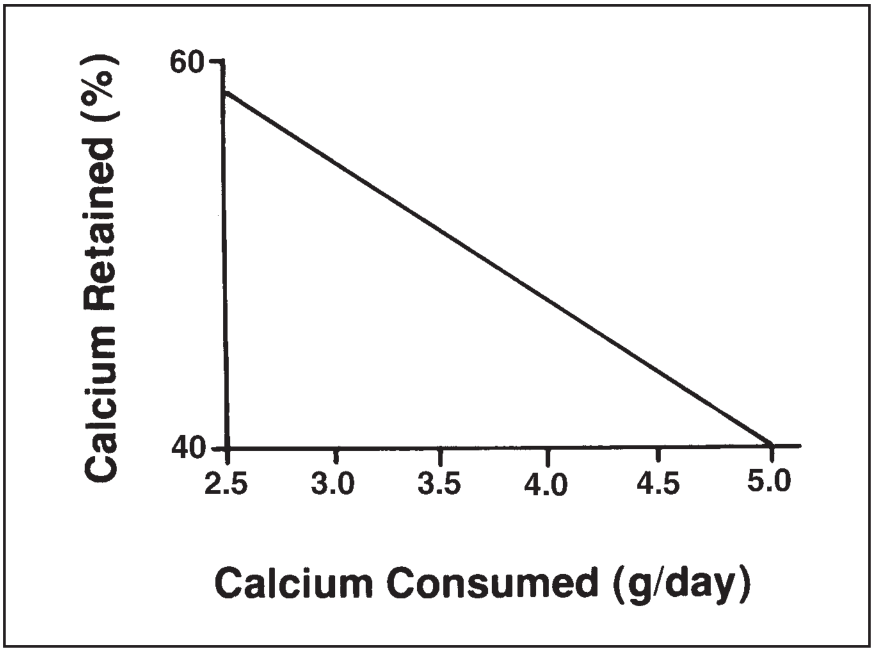
sary for calcifying the first egg produced. In practice, there is considerable variation in formulation and time of using prelay diets, and to some extent this confusion relates to defining sexual maturity *per se*. Historically, prelay diets were fed from about 2 weeks prior to expected maturity, up to the time of 5% egg production. With early, rapid and hopefully synchronized maturation with today's strains, we rarely have the opportunity to feed for 2 weeks prior to maturity. Likewise, it is unwise to feed inadequate levels of calcium when flocks are at 5% production. One of the major management decisions today is the actual need for prelay diets, or whether pullets can sustain long-term shell quality when moved from grower diet directly to a high calcium layer diet.

The bird's skeleton contains around 1 g of medullary calcium that is available for shell calcification on any one day. This calcium is continually replenished between successive ovulations, and in times of inadequate calcium repletion, the medullary reserve may be maintained at the expense of structural cortical bone. Around 60-70% of the medullary calcium reserves are located in the long bones, and so long-term problems of calcium deficiency can lead to lameness and cage layer fatigue.

Prelay diets normally contain 2-2.5% calcium, and when fed over a 10-14 d period provide the bird with the opportunity to deposit medullary bone. This bone deposition coincides with follicular maturation and is under the control of both estrogens and androgens. The latter hormone seems essential for medullary bone growth, and its presence is manifested in growth of the comb and wattles. Consequently, there will be little medullary deposition, regardless of diet calcium level, if the birds are not showing comb and wattle development and this stage of maturity should be the cue for increasing the bird's calcium intake.

Because egg production is an 'all or none' event, the production of the first egg obviously places a major strain on the bird's metabolism when it has to contend with a sudden 2 g loss of calcium from the body. Some of this calcium will come from the medullary bone, and so the need to establish this bone reserve prior to first egg. The heaviest pullets in a flock will likely be the first to mature, and so it is these birds that are most disadvantaged if calcium metabolism is inadequate. If these early maturing pullets receive a 1% calcium grower diet at the time they are producing their first few eggs, they will only have a sufficient calcium reserve to produce 2-3 eggs. At this time, they will likely stop laying, or less frequently continue to lay and exhibit cage layer fatigue. If these earlier maturing birds stop laying, they do so for 4-5 days, and then try to start the process again. The bird goes through very short clutches, when at this time she is capable of a very prolonged 30 – 40 egg first clutch. Advocates of prolonged feeding of grower diets suggest that it makes the bird more efficient in the utilization or absorption of calcium, such that when she is eventually changed to a layer diet, improved efficiency continues for some time, with the bird having more calcium available for shell synthesis. Figure 3.6 indicates that percentage calcium absorption from the diet does decline with an increased level of calcium in the diet.

Fig. 3.6 Relationship between calcium intake and calcium retention.



However, with 40% retention of 5 g of calcium consumed daily, there will be greater absolute calcium retention (2 g/d) than the bird consuming 2.5 g Ca/d and exhibiting 60% efficiency of retention (1.5 g retained/d). There is also no evidence to support the suggestion of carry over of this higher efficiency during early egg production. If 1% calcium grower diets are used around the time of maturity, then these diets should not be used after the appearance of first egg, and to 0.5% production at the very latest. It must be remembered that under commercial conditions, it is very difficult to precisely schedule diet changes, and so decisions for diet change need to precede actual time of diet change, such that production does not reach 5 – 10% before birds physically receive the calcium enriched diets.

Prelay diets provide more calcium than do most grower diets, but still not enough Ca for sustained production. Prelay diets should allow the build up of medullary reserves without adversely influencing general mineral metabolism. However, as previously discussed for grower diets, 2 – 2.5% calcium prelay diets are inadequate for sustained egg production, and should not be fed beyond 1% egg production. The main disadvantage of prelay diets is that they are used for a short period of time, and many producers do not want the bother of handling an extra diet at the layer farm. There is also a reluctance by some producers with multi-age flocks, at one site, to use prelay diets where delivery of diets with 2% calcium to the wrong flock on site can have disastrous effects on production.

Simply in terms of calcium metabolism, the most effective management program is early introduction of the layer diet. Such high calcium diets allow sustained production of even the earliest maturing birds. As previously mentioned, higher calcium diets fed to immature birds,

lead to reduced percentage retention, although absolute retention is increased (Table 3.33).

Feeding layer diets containing 3.5% calcium, prior to first egg, therefore results in a slight increase in calcium retention of about 0.16 g/d relative to birds fed 0.9% calcium grower diets at this time. Over a 10 d period, however, this increased accumulation is equivalent to the output in 1 egg. Since there is only about 1 g of mobile medullary calcium reserve in the mature bird, then the calcium retention values shown in Table 3.33 suggest accumulation of some cortical bone at this time.

Early introduction of layer diets is therefore an option for optimizing the calcium retention of the bird. However, there has been some criticism leveled at this practice. There is the argument that feeding excess calcium prior to lay imposes undue stress on the bird's kidneys, since this calcium is in excess of her immediate requirement and must be excreted. In the study detailed in Table 3.33, there is increased excreta calcium. However, kidney histology from these birds throughout early lay revealed no change due to prelay calcium feeding. Recent evidence suggests that pullets must be fed a layer diet from as early as 6 – 8 weeks of age before any adverse effect on kidney structure is seen (see following section on urolithiasis). It seems likely that the high levels of excreta calcium shown in Table 3.33 reflect fecal calcium, suggesting that excess calcium may not even be absorbed into the body, merely passing through the bird with the undigested feed. This is perhaps too simplistic a view, since there is other evidence to suggest that excess calcium may be absorbed by the immature bird at this time. Such evidence is seen in the increased water intake of birds fed layer diets prior to maturity (Figure 3.7).

Early introduction of a high calcium layer diet seems to result in increased water intake, and a resultant increase in excreta moisture. Unfortunately this increased water intake and wetter manure seems to persist throughout the laying cycle of the bird, (Table 3.34). These data suggest that birds fed high calcium layer diets during the prelay period will produce manure that contains 4 – 5% more moisture than birds fed 1% calcium grower or 2% calcium prelay diets. There are reports of this problem being most pronounced under heat stress conditions. A 4-5% increase in manure moisture may not be problematic under some conditions, although for those farms with a chronic history of wet layer manure, this effect may be enough to tip the balance and

Table 3.33 Effect of % diet calcium fed to birds immediately prior to lay on calcium retention

Diet Ca (%)	*Daily Ca retention (g)*	*Excreta Ca (% dry matter)*
0.9	*0.35*	*1.4*
1.5	*0.41*	*3.0*
2.0	*0.32*	*5.7*
2.5	*0.43*	*5.9*
3.0	*0.41*	*7.5*
3.5	*0.51*	*7.7*

Fig. 3.7 Effect of introducing a 4% calcium layer diet at 112 days (_____) and at 138 (_ _ _ _) on daily water intake.

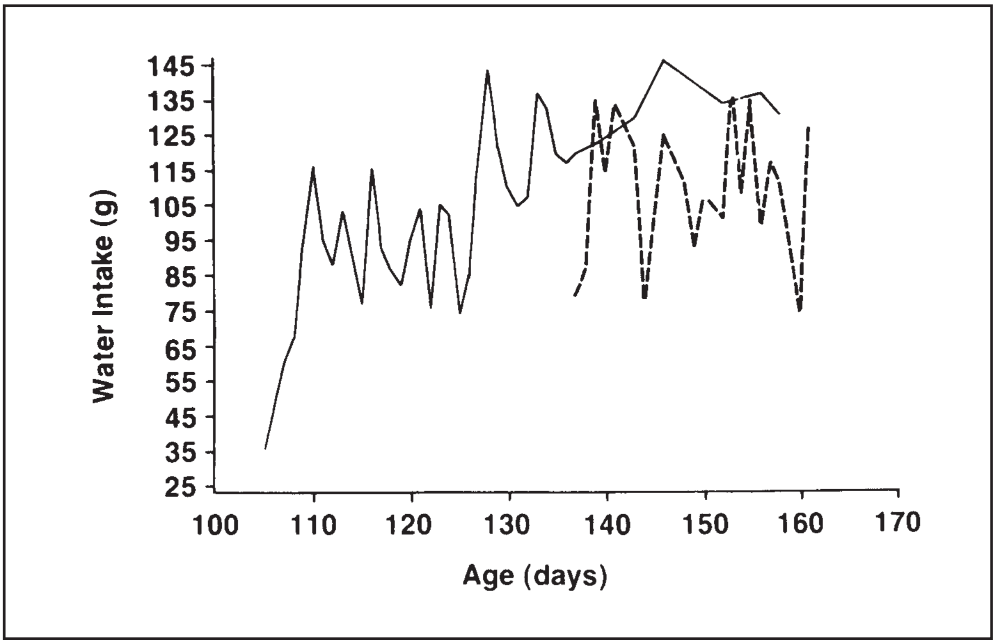


Table 3.34 Effect of prelay calcium level on excreta moisture (%)

Prelay diet Ca (%) (16 – 19 weeks)[1]	Bird age (d) 147	175	196	245
1.0	71.4	78.7	75.3	65.5
2.0	71.6	77.2	73.9	63.9
3.0	72.1	77.7	74.1	63.9
4.0	77.0	80.0	76.0	69.4

[1] *All birds fed 4.0% Ca after 20 weeks of age*

produce a problem. The current trend of feeding even higher calcium levels to laying hens may accentuate this problem, and so dictate the need for prelay diets with more moderate levels of calcium.

In summary, the calcium metabolism of the earliest maturing birds in a flock should be the criterion for selection of calcium levels during the prelay period. Prolonged feeding of low-calcium diets is not recommended. Early introduction of layer diets is ideal, although where wet manure may be a problem, a 2% calcium prelay diet is recommended. There seems to be no problem with the use of 2% calcium prelay diets, as long as birds are consuming a high calcium layer diet no later than at 1% egg production.

ii) Prelay body weight and composition –
Prelay diets are often formulated and used on the assumption that they will improve body weight and/or body composition, and so correct problems arising with the prior growing program. Body weight

and body condition should not really be considered in isolation, although at this time, we do not have a good method of readily assessing body condition in the live pullet. For this reason our main emphasis at this time is directed towards body weight.

Pullet body weight is the universal criterion used to assess growing program. Each strain of bird has a characteristic mature body weight that must be reached or surpassed for adequate egg production and egg mass output. In general, prelay diets should not be used in an attempt to manipulate mature body size. The reason for this is that for most flocks, it is too late at this stage of rearing to meaningfully influence body weight.

However, if underweight birds are necessarily moved to a layer house, then there is perhaps a need to manipulate body weight prior to maturity. With black-out housing, this can some-times be achieved by delaying photostimulation – this option is becoming less useful in that both Leghorns and brown egg strains are maturing early without any light stimulation. If prelay diets are used in an attempt to correct rearing mismanagement, then it seems as though the bird is most responsive to energy. This fact fits in with the effect of estrogen on fat metabolism, and the significance of fat used for liver and ovary development at this time. While using high nutrient density prelay diets may have a minor effect in manipulating body weight, it must be remembered that this late growth spurt (if it occurs) will not be accompanied by any meaningful change in skeletal growth. This means that in extreme cases, where birds are very light weight and of small stature at say, 16 weeks of age, then the end result of using high nutrient dense prelay diets may well be pullets of correct body weight, but of small stature. Pullets with a short shank length seem more prone to prolapse/pick-out, and so this is another example of the limitations in the use of high nutrient dense prelay diets.

While body composition at maturity may well be as important as body weight at this age, it is obviously a parameter that is difficult to quantitate. There is no doubt that energy is likely the limiting nutrient for egg production of all strains of bird, and at peak egg numbers, feed may not be the sole source of energy. Labile fat reserves seem essential to augment feed sources that are inherently limited by low feed intake. These labile fat reserves become critical during situations of heat stress or general hot weather conditions. Once the bird starts to produce eggs, then its ability to build fat reserves is greatly limited. Obviously, if labile fat reserves are to be of significance, then they must be deposited prior to maturity. As with most classes of bird, the fat content of the pullet can best be manipulated through changing the energy:protein balance of the diet. If labile fat reserves are thought necessary, then high energy, high fat prelay diets should be considered. As previously stated, this scenario could well be beneficial if peak production is to coincide with periods of high environmental temperature.

The requirement for a specific body composition at the onset of maturity has not been adequately established. With mammals, onset and function of normal estrus activity is dependent on attainment of a certain body fat content. In humans, for example, onset of puberty will not occur if body fat content is much less than 14%. No such clear cut relationship has emerged with egg layers. Work conducted with broiler breeders, in fact, indicates a more definite relationship between lean body mass and maturity, rather than fat content and maturity.

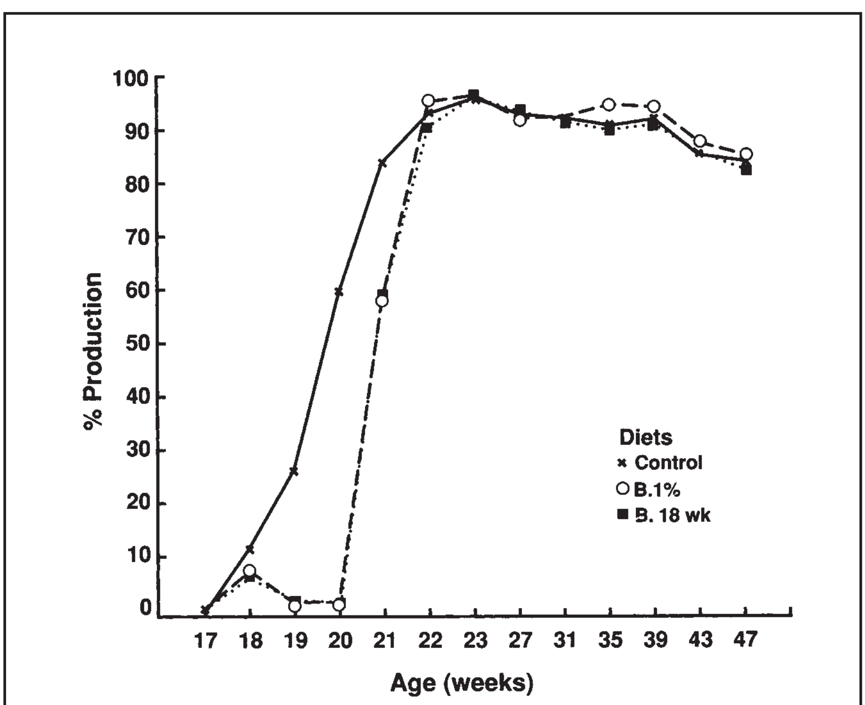
iii) Early egg size – Egg size is greatly influenced by the size of the yolk that enters the oviduct. In large part this is influenced by body weight

of the bird and so factors described previously for mature body weight can also be applied to concerns with early egg size. There is a general need for as large an early egg size as is possible. Most attempts at manipulating early egg size have met with limited success. Increased levels of linoleic acid in prelay diets may be of some use, although levels in excess of the usual 1% found in most diets produce only marginal effects on early egg size. From a nutritional standpoint, egg size can best be manipulated with diet protein, and especially methionine concentration. It is logical, therefore to consider increasing the methionine levels in prelay diets.

iv) Pre-pause – In some countries, and most notably Japan, pre-pause feeding programs are used to maximize early egg size. The idea behind these programs is to withdraw feed, or feed a very low nutrient dense diet at the time of sexual maturity. This somewhat unorthodox program is designed to 'pause' the normal maturation procedure, and at the same time to stimulate greater egg size when production resumes after about 10-14 days. This type of prelay program is therefore most beneficial where early small egg size is economically undesirable.

Pre-pause can be induced by simply withdrawing feed, usually at around 1% egg production. Under these conditions, pullets immediately lose weight, and fail to realize normal weight-for-age when refed. Egg production and feed intake normalize after about 4 weeks, although there is 1-1.5 g increase in egg size. Figure 3.8 shows the production response of Leghorn pullets fed only wheat bran from 18 weeks (or 1% egg production) through to 20 weeks of age.

Fig. 3.8 Early egg production of pullets fed wheat bran at 1% egg production or at 18 weeks of age.



The most noticeable effects resulting from use of a pre-pause diet such as wheat bran, are a very rapid attainment of peak egg production and an increase in egg size once refeeding commences. This management system could therefore be used to better synchronize onset of production (due to variance in body weight), to improve early egg size or to delay production for various management related decisions. The use of such pre-pause management will undoubtedly be affected by local economic considerations, and in particular the price of small vs. medium vs. large grade eggs.

v) Urolithiasis – Kidney dysfunction often leads to problems such as urolithiasis that some-times occurs during the late growing phase of the pullet or during early egg production. While infectious bronchitis can be a confounding factor, urolithiasis is most often induced by diet mineral imbalance in the late growing period. At post-mortem, one kidney is often found to be enlarged and contain mineral deposits known as uroliths. Some outbreaks are correlated with a large increase in diet calcium and protein in layer vs. grower diets, coupled with the stress of physically moving pullets at this time, and being subjected to a change in the watering system (usually onto nipples in the laying cages). The uroliths are most often composed of calcium-sodium-urate.

The occurrence is always more severe when immature pullets are fed high calcium diets for an extended period prior to maturity. For example, urolithiasis causing 0.5% weekly mortality often occurs under experimental conditions when pullets are fed layer diets from 10-12 weeks of age (relative to maturity at 18-19 weeks). However, there is no indication that early introduction of a layer diet for just 2-3 weeks prior to maturity is a causative factor.

Because diet electrolytes can influence water balance and renal function, it is often assumed that electrolyte excess or deficiency may be predisposing factors in urolithiasis or gout. Because salts of uric acid are very insoluble, then the excretion of precipitated urate salts could serve as a water conservation mechanism, especially when cations are excreted during salt loading or when water is in short supply. When roosters are given saline water (1% NaCl) and fed high protein diets, uric acid excretion rates are doubled compared to birds offered the high protein diet along with non-saline drinking water. Because uric acid colloids are negatively charged, they attract cations such as Na, and so when these are in excess, there is an increased excretion via urates, presumably at the expense of conventional NH_4 compounds. There is some evidence of an imbalance of Na+K:Cl levels influencing kidney function. When excess Na+K relative to Cl is fed, a small percentage of the birds develop urolithiasis. It is likely that such birds are excreting a more alkaline urine, a condition which encourages mineral precipitation and urate formation.

As previously described, Urolithiasis occurs more frequently in laying hens fed high levels of calcium well in advance of sexual maturity. Feeding prelay (2-2.5% Ca) or layer diets containing 4-5% calcium for 2-3 weeks prior to first egg is usually not problematic, and surprisingly, uroliths rarely form in adult male breeders fed high calcium diets. High levels of crude protein will increase plasma uric acid levels, and potentially provide conditions conducive to urate formation.

In humans, urolith formation (gout) can be controlled by adding urine acidifiers to the diet. Studies with pullets show similar advantages. Adding 1% NH_4Cl to the diet results in a more

acidified urine, and uroliths rarely form under these conditions. Unfortunately, this treatment results in increased water intake, and associated wet manure. One of the potential problems in using NH_4Cl once the birds start laying is that the metabolic acidosis is detrimental to eggshell quality especially under conditions of heat stress. Such treatment also assumes the kidney can clear the increased load of H+, and for a damaged kidney, this may not always be possible. As a potential urine acidifier without such undesirable side effects, several researchers have studied the role of Alimet® a methionine analogue. In one study, pullets were fed diets containing 1 or 3% calcium with or without Alimet® from 5-17 weeks. Birds fed the 3% calcium diet excreted alkaline urine containing elevated calcium concentrations together with urolith formation and some kidney damage. Feeding Alimet® acidified the urine, but did not cause a general metabolic acidosis. Alimet® therefore reduced kidney damage and urolith formation without causing acidosis or increased water consumption. Urine acidification can therefore be used as a prevention or treatment of urolithiasis, and this can be accommodated without necessarily inducing a generalized metabolic acidosis. From a nutritional viewpoint, kidney dysfunction can be minimized by not oversupplying nutrients such as calcium, crude protein and electrolytes for too long a period prior to maturity.

g) Lighting programs

Photoperiod has a dramatic influence on the growth and body composition of the growing pullet and so light programs must be taken into account when developing feeding programs. In terms of pullet management, day length has two major effects, namely the development of reproductive organs and secondly a change in feed intake. It is well known that birds reared on a step-up or naturally increasing day length will mature earlier than those reared on a constant day length. Similarly, if birds are subjected to a step-down day length much after 12 weeks of age, they will likely exhibit delayed sexual maturity. The longer the photoperiod, the longer the time that birds have to eat feed, and so usually this results in heavier birds. Table 3.35 shows the growth rate and feed intake of pullets reared on constant day lengths of 6, 8, 10 or 12 hours to 18 weeks of age. For Leghorn pullets, each extra hour of day length during rearing increased body weight by about 20 g and feed intake by 100 g. For brown egg pullets there was a 13 g increase in weight and 70 g increase in feed intake for each hour of extra light.

Table 3.35 Effect of day length during rearing on growth and feed intake of pullets

Hours of light/d 7d-18 wks	*Leghorn*			*Brown egg*		
	18 wk wt (g)	*Feed intake (kg)*	*17 wk egg production (%)*	*18 wk wt (g)*	*Feed intake (kg)*	*17 wk egg production (%)*
6	1328[c]	6.14	0	1856[b]	7.53	12
8	1376[b]	6.00	1.2	1930[ab]	7.83	12
10	1425[a]	6.30	2.0	1889[ab]	7.60	10
12	1455[a]	6.71	3.4	1953[a]	8.06	12

Longer photoperiods may be beneficial in hot weather situations where feed intake of pullets is often depressed. As the day length for the growing pullet is increased, there is a reduction in age at maturity. Research data suggests earlier maturity with constant rearing day lengths up to 16-18 hours per day, although longer daylengths such as 20-22 hours per day seem to delay maturity. Another potential problem with longer day length during rearing is that it allows less potential for light stimulation when birds are moved to laying facilities. However, in equatorial regions where maximum day length fluctuates between 11-13 hours, many birds are managed without any light stimulation. In fact, under such hot weather, high light intensity conditions, excessive stimulation often results in prolapse and blowouts. In these situations if light stimulation is given, it should follow rather than lead, the onset of egg production. It seems that for modern strains of birds, light stimulation at 'maturity' is not always necessary for adequate layer performance. In a recent trial, we have shown some advantages to constant 14 h photoperiods for the entire life of the bird vs. an 8 h rearing photoperiod followed by a 14 h layer photoperiod (Table 3.36). Pullets that were grown on constant 14 h light and not given any extra day length at maturity produced fewer eggs mainly due to reduced peak production. However, this flatter peak was associated with a significant increase in egg size and a significant improvement in shell quality (lower eggshell deformation). The reason for improved shell quality is not clear, although we have seen this with other flocks that fail to show adequate sustained peaks – maybe giving up a few eggs at peak is a means of improving shell quality. The increased egg size for birds on the constant 14 h photoperiod is undoubtedly due to birds being heavier at maturity, and then eating more feed throughout the laying period.

When birds are light stimulated prior to first egg, their age at light stimulation will have an effect on age at first egg. Our data suggest that after98 d of age, for each 1 d delay in age at light stimulation, first egg will occur about 0.5 d later (Figure 3.9). This means that light stimulating a pullet at 105 d rather than 125 d, will likely result in earlier maturity by about 10 days. At this time, it is important to re-emphasize the previous discussion concerning adequacy of body weight and body condition before considering earlier light stimulation. Another program that can be used to stimulate growth is 'step-down' lighting (Figure 3.10).

In Figure 3.10, birds are given 23 hr light/d for the first week and then day length is reduced by about 1 h each week until 10 h per day is achieved, at which time it is held constant. When birds are in open-sided houses, the minimum day length achieved is dictated by the maximum natural day length during this time. Birds can then

Table 3.36 Effect of rearing daylength on subsequent layer performance

Photoperiod		*336d egg*	*Egg weight*	*Shell deformation*
Rearing	*Laying*	*production*	*(g)*	*(µg)*
8h	*14h*	*271[a]*	*58.4[b]*	*26.5[a]*
14h	*14h*	*256[b]*	*60.3[a]*	*25.4[b]*

Fig. 3.9 Age at light stimulation (8-14 hr) and sexual maturity.

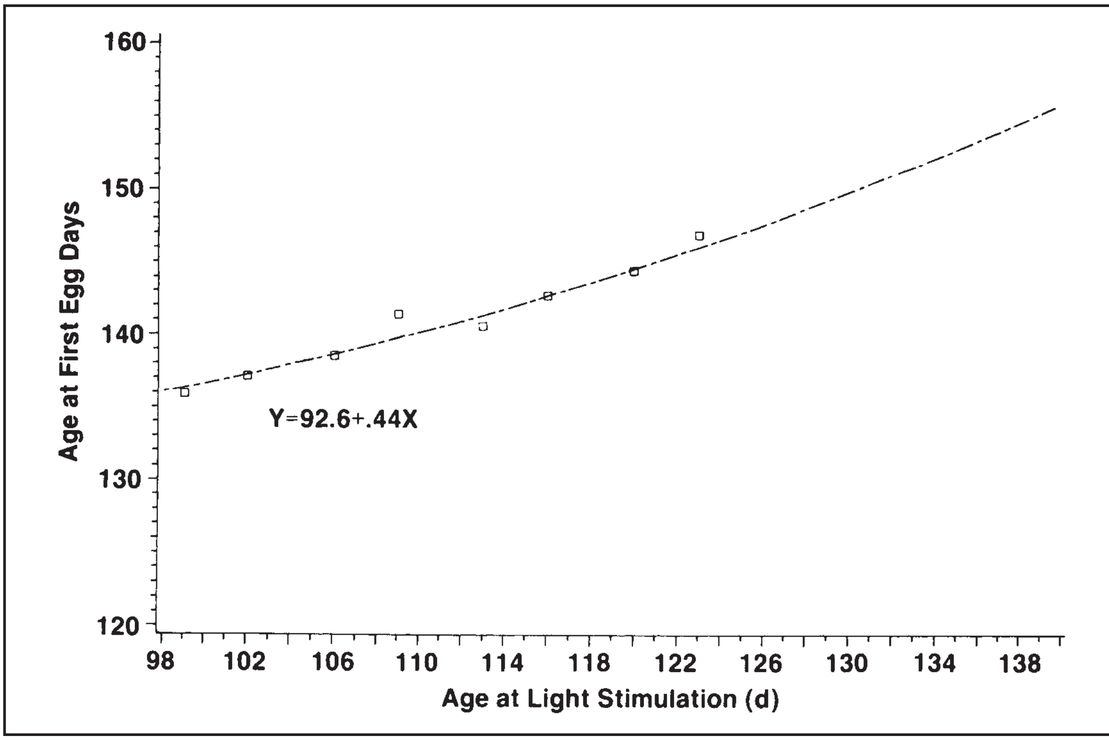
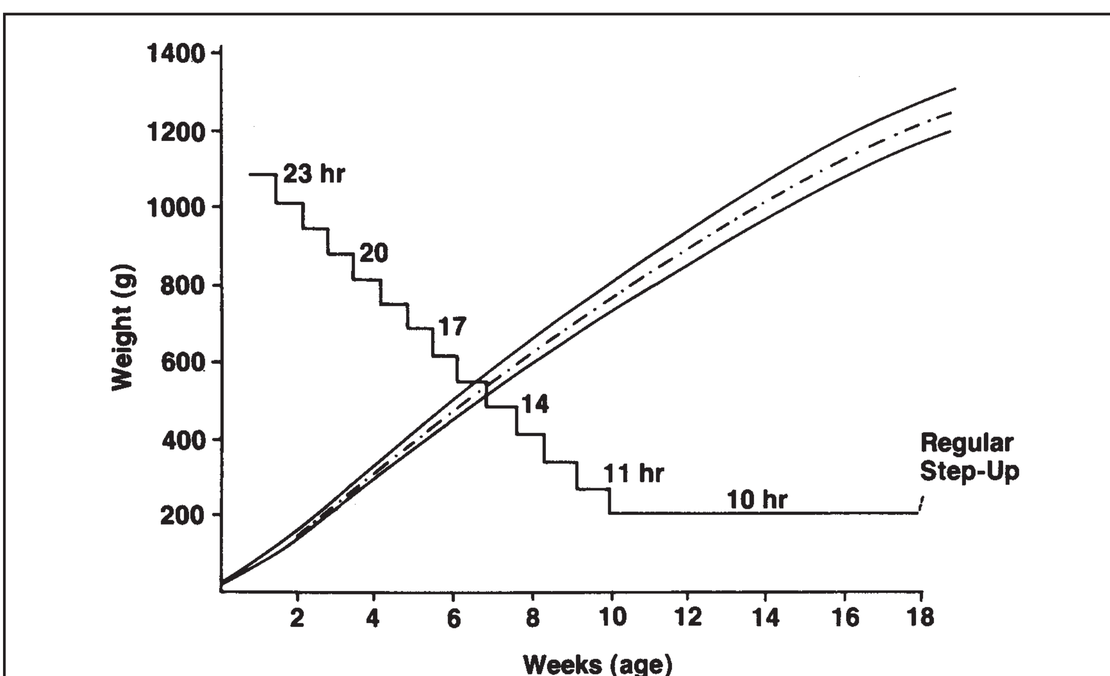


Fig. 3.10 Step-down lighting.



be photostimulated at the normal time. The step-down program has the advantage of allowing the pullets to eat feed for considerably more time each day during their early development. In hot weather conditions, this long day length means that birds are able to eat more feed during cooler parts of the day. The system should not be confused with historical step-down lighting programs that continued step-down until 18-20 weeks; these older programs were designed to delay maturity. For the program in Figure 3.10, maturity will not be affected as long as the step-down regime is stopped by 10 – 12 weeks of age, i.e. before the pullet becomes most sensitive to changes in day length. The step-down lighting program is one of the simplest ways of increasing growth rate in pullets and is practical with both blackout and open-sided buildings.

Keshavarz (1998) shows increased body weight of 15 week old pullets grown on a step-down lighting program of 23 to 8 h by 16 weeks (Table 3.37). In this study the step-down photoperiod was continued through to 16 weeks, and this delayed sexual maturity resulting in a 1 g increase in egg size.

h) Feed restriction

Feed restriction may be necessary for controlling the weight of brown egg pullets during cooler winter months. The goal of any restriction program is to ensure optimum weight-for-age at sexual maturity. Because many strains of brown egg birds are now maturing very early and since their mature body size has been decreased, the need for restriction occurs less frequently. A major concern with restriction programs is maintenance of flock uniformity. With a mild restriction program, birds can be allowed to 'run-out' of feed one day per week and usually this will do little harm to uniformity. If it is necessary to impose a greater degree of feed restriction on a daily basis, then it is important to ensure rapid and even feed distribution, as subsequently discussed for broiler breeders (Chapter 5). Feed restriction should be relaxed if birds are subjected to any stresses such as beak trimming, vaccination, general disease challenges or substantial reduction in environmental temperature. An alternative management procedure for overweight birds is to schedule an earlier light stimulation and move to layer cages (see Figure 3.4).

Brown egg pullets do seem to consume less energy and so are smaller when given lower energy diets. For example providing pullets grower-developer diets at 2750 vs. 3030 kcal ME/kg resulted in an 8% reduction in energy intake and 4% reduction in body weight. These same diets fed to Leghorn pullets resulted in just 4% reduction in energy intake of the lower energy diet with virtually no change in body weight. Reduced nutrient density should therefore be considered in conjunction with physical feed restriction, for controlled growth of brown egg pullets.

Table 3.37 Effect of continuous weekly step-down lighting on pullet development

Rearing photoperiod	*Body wt (15 wk) (g)*	*18 wk uniformity (%)*	*Feed intake (0-18 wk) (kg)*	*Age first egg (d)*
8 h	*1070[a]*	*69*	*5.98*	*130*
23 to 8 h @ 16 wk[1]	*1120[b]*	*78*	*6.20*	*140*

[1]1 hour decrease/wk *Adapted from Keshavarz (1998)*

Suggested Readings

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CHAPTER 4

FEEDING PROGRAMS FOR LAYING HENS

Page

4.1 Diet specifications and formulations

Diet specifications for laying hens are shown in Table 4.1, and are categorized according to age and feed intake. There is no evidence to suggest that the energy level of diets needs to be changed as the birds progress through a laying cycle. The layer's peak energy needs are most likely met at around 35 weeks of age, when production and daily egg mass output are maximized. However, the layer quite precisely adjusts its intake according to needs for energy and so variable energy needs are accommodated by change in feed intake.

Most Leghorn strains will now commence egg production with feed intakes as low as 80 – 85 g/day, and it is difficult to formulate diets for such a small appetite. For brown egg strains, initial feed intake will be around 92 - 95 g/day and so formulation is more easily accommodated. For all diets, maintaining the balance of all nutrients to energy is the most important consideration during formulation.

In general terms, diet nutrient concentrations decrease over time, with the notable exception of the need for calcium. Thus, diet protein and amino acids expressed as a percent of the diet or as a ratio to energy, decline as the bird progresses through the laying cycle. In order to sustain shell quality, it is important to increase diet calcium level, and to concomitantly decrease diet phosphorus level, as the bird gets older. The need for less methionine is partially related to the need for tempering late-cycle increase in egg size, since this is usually uneconomical regarding egg pricing and larger eggs have thinner shells. There is little evidence for change in needs for vitamins and trace minerals as birds get older, and so a single premix specification is shown in Table 4.1. For most of the B-vitamins, it is possible to phase feed with up to 30% reduction by the end of the laying cycle.

Examples of layer diets using corn, wheat, or sorghum as the main energy source and with or without meat meal, are shown in Tables 4.2 – 4.5. The diets are categorized according to age of bird. It is difficult to achieve desired energy level in Phase I diets (Table 4.2) without resorting to inclusion of significant quantities of fat. If fat supply and quality is questionable, it may be advisable to reduce the energy level of the diet (and also all other nutrients in the same ratio), by up to 50 – 70 kcal ME/kg.

Table 4.1 Diet specifications for layers

Approximate age	18-32 wks		32-45 wks		45-60 wks		60-70 wks	
Feed intake (g/bird/day)	90	95	95	100	100	105	100	110
Crude Protein (%)	20.0	19.0	19.0	18.0	17.5	16.5	16.0	15.0
Metabolizable Energy (kcal/kg)	2900	2900	2875	2875	2850	2850	2800	2800
Calcium (%)	4.2	4.0	4.4	4.2	4.5	4.3	4.6	4.4
Available Phosphorus (%)	0.50	0.48	0.43	0.4	0.38	0.36	0.33	0.31
Sodium (%)	0.18	0.17	0.17	0.16	0.16	0.15	0.16	0.15
Linoleic acid (%)	1.8	1.7	1.5	1.4	1.3	1.2	1.2	1.1
Methionine (%)	0.45	0.43	0.41	0.39	0.39	0.37	0.34	0.32
Methionine + Cystine (%)	0.75	0.71	0.70	0.67	0.67	0.64	0.6	0.57
Lysine (%)	0.86	0.82	0.80	0.76	0.78	0.74	0.73	0.69
Threonine (%)	0.69	0.66	0.64	0.61	0.60	0.57	0.55	0.52
Tryptophan (%)	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.14
Arginine (%)	0.88	0.84	0.82	0.78	0.77	0.73	0.74	0.70
Valine (%)	0.77	0.73	0.72	0.68	0.67	0.64	0.63	0.60
Leucine (%)	0.53	0.50	0.48	0.46	0.43	0.41	0.40	0.38
Isoleucine (%)	0.68	0.65	0.63	0.60	0.58	0.55	0.53	0.50
Histidine (%)	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.11
Phenylalanine (%)	0.52	0.49	0.48	0.46	0.44	0.42	0.41	0.39

Vitamins (per kg of diet):	
Vitamin A (I.U)	8000
Vitamin D_3 (I.U)	3500
Vitamin E (I.U)	50
Vitamin K (I.U)	3
Thiamin (mg)	2
Riboflavin (mg)	5
Pyridoxine (mg)	3
Pantothenic acid (mg)	10
Folic acid (mg)	1
Biotin (µg)	100
Niacin (mg)	40
Choline (mg)	400
Vitamin B_{12} (µg)	10
Trace minerals (per kg of diet):	
Manganese (mg)	60
Iron (mg)	30
Copper (mg)	5
Zinc (mg)	50
Iodine (mg)	1
Selenium (mg)	0.3

Table 4.2 Examples of Phase 1 layer diets (18-32 wks)

	1	2	3	4	5	6
Corn	*507*	*554*				
Wheat			*517*	*619*		
Sorghum					*440*	*373*
Wheat shorts			*42*		*68*	*184*
Meat meal		*70*		*70*		*70*
Soybean meal	*327*	*245*	*261*	*171*	*311*	*214*
Fat	*45*	*31*	*60*	*40*	*60*	*59*
*DL-Methionine**	*1.2*	*1.2*	*1.6*	*1.5*	*1.8*	*1.8*
Salt	*3.6*	*2.6*	*3.0*	*2.0*	*3.6*	*2.6*
Limestone	*99.5*	*92.3*	*100*	*94*	*100*	*93*
Dical Phosphate	*15.7*	*2.9*	*14.4*	*1.5*	*14.6*	*1.6*
*Vit-Min Premix***	*1*	*1*	*1*	*1*	*1*	*1*
Total (kg)	*1000*	*1000*	*1000*	*1000*	*1000*	*1000*
Crude Protein (%)	*20*	*20*	*20*	*20*	*20*	*20*
ME (kcal/kg)	*2900*	*2900*	*2900*	*2900*	*2900*	*2900*
Calcium (%)	*4.2*	*4.2*	*4.2*	*4.2*	*4.2*	*4.2*
Av Phosphorus (%)	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*
Sodium (%)	*0.18*	*0.18*	*0.18*	*0.18*	*0.18*	*0.18*
Methionine (%)	*0.45*	*0.46*	*0.45*	*0.45*	*0.45*	*0.45*
Meth + Cystine (%)	*0.76*	*0.75*	*0.77*	*0.76*	*0.8*	*0.78*
Lysine (%)	*1.14*	*1.15*	*1.12*	*1.05*	*1.17*	*1.16*
Threonine (%)	*0.86*	*0.83*	*0.75*	*0.7*	*0.78*	*0.75*
Tryptophan (%)	*0.28*	*0.26*	*0.30*	*0.28*	*0.28*	*0.26*

** or eqivalent MHA*
*** with choline*

Table 4.3 Examples of Phase 2 layer diets (32-45 wks)

	1	2	3	4	5	6
Corn	536	581				
Wheat			586	508		
Sorghum					419	382
Wheat shorts			8	123	118	200
Meat meal		70		60		65
Soybean meal	301	220	233	156	279	192
Fat	39	24.6	50	50	60	56
*DL-Methionine**	0.9	1.1	1.3	1.2	1.5	1.5
Salt	3.3	2.3	2.7	1.8	3.4	2.5
Limestone	106	100	107	99	107	100
Dical Phosphate	12.8		11.0		11.1	
*Vit-Min Premix***	1	1	1	1	1	1
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	19	19	19	19	19	19
ME (kcal/kg)	2875	2875	2875	2875	2875	2875
Calcium (%)	4.4	4.4	4.4	4.4	4.4	4.4
Av Phosphorus (%)	0.43	0.44	0.43	0.44	0.43	0.44
Sodium (%)	0.17	0.17	0.17	0.17	0.17	0.17
Methionine (%)	0.41	0.42	0.41	0.41	0.41	0.41
Meth + Cystine (%)	0.70	0.70	0.72	0.70	0.74	0.72
Lysine (%)	1.07	1.07	1.04	1.04	1.08	1.09
Threonine (%)	0.82	0.79	0.71	0.67	0.74	0.71
Tryptophan (%)	0.26	0.25	0.28	0.26	0.26	0.25

** or eqivalent MHA*
*** with choline*

Table 4.4 Examples of Phase 3 layer diets (45-60 wks)

	1	2	3	4	5	6
Corn	584	626				
Wheat			648	571		
Sorghum					550	483
Wheat shorts				113	35	143
Meat meal		60		50		55
Soybean meal	261	190	187	115	248	169
Fat	29	14.8	40	40	40.5	40
*DL-Methionine**	1	1.2	1.3	1.5	1.5	1.5
Salt	3	2	2.5	1.5	3.2	2.5
Limestone	111	105	111	107	111	105
Dical Phosphate	10		9.2		9.8	
*Vit-Min Premix***	1	1	1	1	1	1
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	17.5	17.5	17.5	17.5	17.5	17.5
ME (kcal/kg)	2850	2850	2850	2850	2850	2850
Calcium (%)	4.5	4.5	4.5	4.5	4.5	4.5
Av Phosphorus (%)	0.38	0.39	0.38	0.38	0.38	0.38
Sodium (%)	0.16	0.16	0.16	0.16	0.16	0.16
Methionine (%)	0.40	0.42	0.39	0.41	0.39	0.39
Meth + Cystine (%)	0.67	0.67	0.67	0.67	0.70	0.68
Lysine (%)	0.95	0.95	0.92	0.93	0.98	0.98
Threonine (%)	0.76	0.73	0.63	0.60	0.68	0.64
Tryptophan (%)	0.24	0.22	0.26	0.24	0.24	0.22

** or eqivalent MHA*
*** with choline*

Table 4.5 Examples of Phase 4 layer diets (60-70 wks)

	1	2	3	4	5	6
Corn	638	619				
Wheat			570	527		
Sorghum					485	467
Wheat shorts		51	126	190	156	200
Meat meal		49		38		42
Soybean meal	221	157	138	90	192	138
Fat	13	9.7	40	40	40	37
DL-Methionine*	0.8	1	1.1	1.2	1.2	1.4
Salt	3	2.3	2.4	1.8	3	2.6
Limestone	115	110	115	111	115	111
Dical Phosphate	8.2		6.5		6.8	
Vit-Min Premix**	1	1	1	1	1	1
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	16	16	16	16	16	16
ME (kcal/kg)	2800	2800	2800	2800	2800	2800
Calcium (%)	4.6	4.6	4.6	4.6	4.6	4.6
Av Phosphorus (%)	0.33	0.35	0.35	0.35	0.35	0.35
Sodium (%)	0.16	0.16	0.16	0.16	0.16	0.16
Methionine (%)	0.36	0.37	0.35	0.36	0.34	0.34
Meth + Cystine (%)	0.60	0.60	0.60	0.60	0.62	0.61
Lysine (%)	0.83	0.83	0.80	0.80	0.85	0.85
Threonine (%)	0.70	0.67	0.57	0.55	0.60	0.59
Tryptophan (%)	0.22	0.20	0.24	0.23	0.21	0.20

** or eqivalent MHA*
*** with choline*

4.2 Feed and energy intake

Feeding programs for layers cannot be developed without consideration for the rearing program as discussed in Chapter 3. Unfortunately, many egg producers purchase point-of-lay pullets from independent pullet growers, and here the goals of the two producers are not always identical. Too often the egg producer is interested in purchasing mature pullets at the lowest possible cost per bird regardless of their condition. For pullet growers to make a profit they must produce birds at the lowest possible cost. With feed representing some 60 to 70% of the cost to produce a pullet, the obvious way for the pullet grower to reduce costs is to save on feed cost. While they may be able to save a small amount of feed by eliminating feed waste or by ensuring that house temperatures are optimum, the only way to save a substantial amount of feed is to place the pullets on a growing program such that feed consumption is reduced and/or cheaper diets are used. Because it is not possible to enhance the efficiency with which pullets convert feed into body weight gain, the net result is a smaller bird at time of transfer. If the birds have been on an increasing light pattern, they might well be mature, as judged from appearance, at the onset of production. However, such pullets must still grow before they reach their optimum weight and condition as a laying hen. Consequently, the egg producer will have to feed this pullet in an attempt to bring the body weight up to normal if a profitable laying flock is to be obtained. If egg producers attempt to save on feed, the result will be underweight birds at peak egg production. This situation leads to smaller eggs, and often lower than normal peak or birds dropping relatively quickly in production shortly past peak as discussed in the previous chapter.

It takes a certain amount of feed to produce a laying hen with optimum body size. If this feed is not consumed in the growing period, it must be fed in the laying house. Of course, one would have to be sure that the pullets are healthy and are not carrying an excess of body fat. However, the problem of excess body fat with today's modern type, early maturing pullet, does not usually occur. Egg producers should also find out as much as possible about the pullets they are purchasing, such as the type of feeding program they have been on, the health status of the flock, and the type of waterers used in rearing. With this type of information, they should be in a better position to ensure a profitable laying flock.

It is now common practice to describe feeding programs for layers according to the level of feed intake. It is well known that under normal environmental and management conditions, feed intake will vary with egg production and/or age of bird, and this must be taken into account when formulating diets. While layers do adjust feed intake according to diet energy level, there is no evidence to suggest that such precision occurs with other nutrients.

The following daily intakes of nutrients are suggested under ideal management and environmental conditions (Table 4.6).

Table 4.6 Daily nutrient needs for Leghorn birds.

		Age (wks)			
		18 – 32	32 – 45	45 – 60	60 – 70
Protein	(g)	20	18.5	17.5	16
Metabolizable energy	(kcal)	260	290	285	280
Calcium	(g)	4.0	4.2	4.4	4.6
Av. Phosphorus	(mg)	550	450	380	330
Methionine	(mg)	500	430	390	340
TSAA	(mg)	830	740	670	600
Lysine	(mg)	950	840	780	730

Table 4.7 Feed intake of Leghorns as influenced by body weight, egg production, egg weight and environmental temperature[1]

Body weight		Egg production		Egg weight		Temperature	
Body wt (g)	Intake (g/d)	Egg production (%)	Intake (g/d)	Egg wt (g)	Intake (g/d)	ºC	Intake (g/d)
1200	92.7	98	100.5	50	90.8	10	102.2
1250	94.9	94	98.8	55	94.0	15	102.1
1300	97.1	90	97.1	60	97.1	20	97.1
1350	99.3	86	95.4	65	100.3	25	92.1
1400	101.5	82	93.8	70	103.4	30	87.1
23g ≡ 1 g		2.4% ≡ 1 g		1.6 g ≡ 1 g		1ºC ≡ 1 g	

[1] Assumes 1300 g body weight, 90% egg production, 60 g egg weight and 20□C as the standard, with diet at 2850 kcal/kg

At any given time, it is necessary to adjust diet specifications according to the actual feed intake of the flock. Within a single strain it is possible to see a ± 15 g variance in feed intake at any age related to stage of maturity, egg mass, body size and most importantly, environmental temperature.

It is possible to predict energy needs, and hence feed intake, based on knowledge of the major variables. The equation most commonly used is described below. Using this equation, Table 4.7 was developed with variable inputs of body weight, egg production, egg weight and environmental temperature. Feed intake was calculated assuming a diet energy level of 2850 kcal ME/kg.

$$\textbf{Energy (kcal ME/bird/day)} = [\textbf{Body weight (kg)}]\,[170 - 2.2 \times {}^{o}\textbf{C}] + [2 \times \textbf{Egg mass/d (g)}] + [5 \times \textbf{Daily weight gain (g)}]$$

For these calculations, one factor at a time was changed, and the standards for other parameters are highlighted across the middle of Table 4.7. For example, in the case of body weight, the effect on feed intake was calculated with 50 g increments of weight from 1200 to 1400 g. For each of these calculations for body weight, egg production was fixed at 90%, egg weight at 60 g and environmental temperature at 20˚C. Likewise, when egg production was the variable considered all other factors remained constant. The summary data appearing as the last row in Table 4.7 show the relative change in each input parameter necessary to change feed intake by one gram/bird/day. Consequently, ± 23 g body weight, ± 2.4% egg production, ±1.6 g egg weight, and ± 1ºC all change feed intake by ± 1 g/bird/day. Of these factors environmental temperature is usually the most variable on a day-to-day basis, and so, is likely responsible for most of the variation in feed intake seen in commercial flocks.

With variable feed intake, it is necessary to adjust the ratios of nutrients to energy to maintain constant intakes of these nutrients. While it is impractical to consider reformulation based on day-to-day fluctuation in environmental temperature, trends in feed intake associated with high vs. low body weight etc. should be accommodated in diet formulation.

A knowledge of feed intake, and the factors that influence it, are therefore essential for any feed management program. To a degree, the energy level of the diet will influence feed intake, although one should not assume the precision of this mechanism to be perfect. In general, birds over consume energy with higher energy diets, and they will have difficulty maintaining normal energy intake when diets of less than 2500 kcal ME/kg are offered. In most instances, under- consumption rather than over-consumption is the problem, and so use of higher energy diets during situations such as heat stress will help to minimize energy insufficiency. Table 4.8 shows the Leghorn bird's response to variable diet energy.

These Leghorn strain birds performed surprisingly well with the diluted diets, and showed an amazing ability to adjust feed intake as diet nutrient density changed, and down to 2600 kcal ME/kg were able to maintain almost constant energy intake. Only at 2450 kcal/kg, which represents a 15% dilution of the original diet, were there indications of failure to consume adequate amounts of energy (or other nutrients?).

Table 4.8 Layer response to diet dilution (19 - 67 wks age)

Diet energy (kcal/kg)[1]	*Feed intake (g/b/d)*			*Feed (kg)*	*Egg*		*Energy intake (Mcal/365d)*
	43 wks	*51 wks*	*65 wks*	*(19 – 67 wk)*	*Number*	*Mass (kg)*	
2900	*100[b]*	*103[bc]*	*103[b]*	*33.9[b]*	*290*	*17.9[a]*	*98.3*
2750	*100[b]*	*103[bc]*	*103[b]*	*34.3[b]*	*294*	*16.9[b]*	*94.7*
2600	*116[a]*	*113[a]*	*109[ab]*	*37.1[a]*	*304*	*17.9[a]*	*96.8*
2450	*112[a]*	*111[a]*	*115[a]*	*37.1[a]*	*302*	*17.3[ab]*	*91.2*

1 *All other nutrients in same ratio to energy across all diets*

Adapted from Leeson et al. (2001)

These birds were maintained at 20 - 22˚C, and it is suspected that the layers may have had difficulty maintaining nutrient intake with the diluted diets if any heat distress conditions occurred.

The diet specifications listed in Table 4.1 show values for crude protein. If soybean meal and corn, wheat or sorghum make up 60 – 70% of the diet, then protein *per se* gives an indication of the likely adequacy of amino acid needs. Obviously formulation to total and digestible amino acids is critical in more precisely meeting the bird's nutrient needs, yet there is still a need for other nitrogen containing nutrients that are variably described as crude protein or non-essential amino acids. Theoretically, a layer diet has to provide only the ten essential amino acids and under ideal conditions, these will be at requirement levels. However, when diets are formulated on this basis, production, and economic returns are reduced, suggesting the need for a 'minimal' level of crude protein. Under commercial conditions, production goals are rarely achieved when crude protein levels much less than 15% are used through the layer cycle regardless of the supply of essential amino acids. Such effects imply a requirement for nitrogen or non-essential amino acids and/or that our assessment of essential amino acid needs are incorrect. As crude protein level of the diet is reduced, regardless of amino acid supply, there is also increase in mortality and reduced feather score (Table 4.9). The feathering of white and especially brown egg birds is adversely affected by low protein diets (lower score).

There is little doubt that body weight at maturity is a major factor influencing feed intake of laying hens. Body weight differences seen at maturity are maintained throughout lay almost regardless of nutrient profile of layer diets. It is therefore difficult to attain satisfactory nutrient intakes with small birds. Conversely, larger birds will tend to eat more, and this may become problematic in terms of the potential for obesity and/or too large an egg towards end of lay. Phase feeding of nutrients can overcome some of these problems, although a more simplistic long-term solution is control over body weight at maturity. Under most economic conditions, 'heavier' birds at maturity are ultimately most economical for table egg production in terms of egg revenue relative to feed costs.

Table 4.9 Effect of crude protein on mortality and feather score

		Feather score (Scale 0-20)	
%CP	*%Cannibalism*	*White*	*Brown*
11.1	*17.6*	*12.4*	*10.7*
12.5	*8.3*	*13.7*	*11.3*
13.8	*5.1*	*13.9*	*12.8*
15.2	*2.7*	*15.0*	*13.1*
16.5	*4.2*	*14.8*	*14.1*
17.9	*0.4*	*14.9*	*14.6*
19.3	*2.5*	*15.9*	*15.0*

Adapted from Ambrosen and Petersen (1997)

Feed management becomes even more critical with earlier and higher sustained peak egg production from today's strains of bird. Energy insufficiency during pre-peak production can cause problems during post-peak production. Egg production curves that show a 5 – 8% reduction after peak are characteristic of birds with insufficient appetite caused by too small a pullet at maturity (Figure 3.1). The reduction in appetite is of concern relative to the adequacy of energy intake. Calculations of energy balance indicate a somewhat precarious balance around the time of peak egg numbers, emphasizing the need for stimulating feed intake and the possibility of providing some labile energy reserves in the form of carcass energy (fat) stores. Tables 4.10 and 4.11 show such calculated values for Leghorn and brown egg strains respectively, and relate these to the required intake of a standard diet.

The significance of energy intake as the limiting nutrient for egg production with modern strains of layer is shown in Figure 4.1. There is a dramatic response to energy intake from 184 – 312 kcal/bird/day, in the form of egg output. At very high energy intakes, there is little apparent response to protein intake over the range of 13 – 21 g/bird/day. Only when energy intake is limiting is there any measurable increase in egg numbers in response to increased protein intake. However, as will be detailed later (Figure 4.13), the converse applies in terms of egg size, when the bird shows a dramatic response to protein intake, and little response to energy intake.

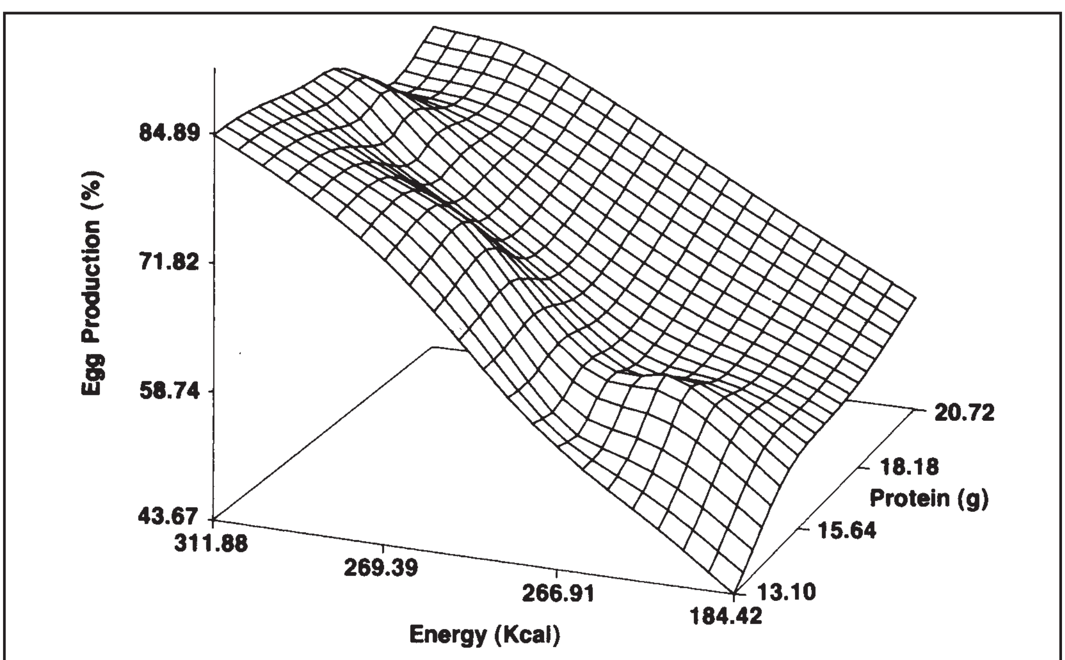
Table 4.10 Energy balance of leghorn pullets during early egg production

Age (wks)	Theoretical Daily Energy Requirement (kcal ME per bird)				Required intake of 17% CP, 2850 ME diet (g/d)
	Maintenance	Growth	Eggs	Total	
16	133	40		177	62
17	137	40		181	64
18	142	40		186	65
19	150	35	5	190	67
20	154	35	10	199	70
21	154	30	24	208	73
22	154	30	44	228	80
23	154	25	57	242	85
24	154	25	78	257	90
25	155	20	85	260	91
26	155	18	87	262	92
27	158	15	92	265	93
28	158	15	95	268	94
29	160	13	97	270	95
30	161	12	100	273	96

Table 4.11 Energy balance of brown egg pullets during early egg production

Age (wks)	*Theoretical Daily Energy Requirement (kcal ME per bird)*				*Required intake of 17% CP, 2850 ME diet (g/d)*
	Maintenance	*Growth*	*Eggs*	*Total*	
16	148	50	2	200	70
17	148	50	8	205	72
18	134	50	30	214	75
19	138	40	50	228	80
20	142	40	60	242	85
21	148	30	70	248	87
22	152	30	80	262	92
23	155	25	95	271	95
24	160	25	96	274	96
25	164	15	97	276	97
26	166	15	98	279	98
27	168	15	99	282	99
28	173	12	100	285	100
29	175	12	101	288	101
30	176	12	102	290	102

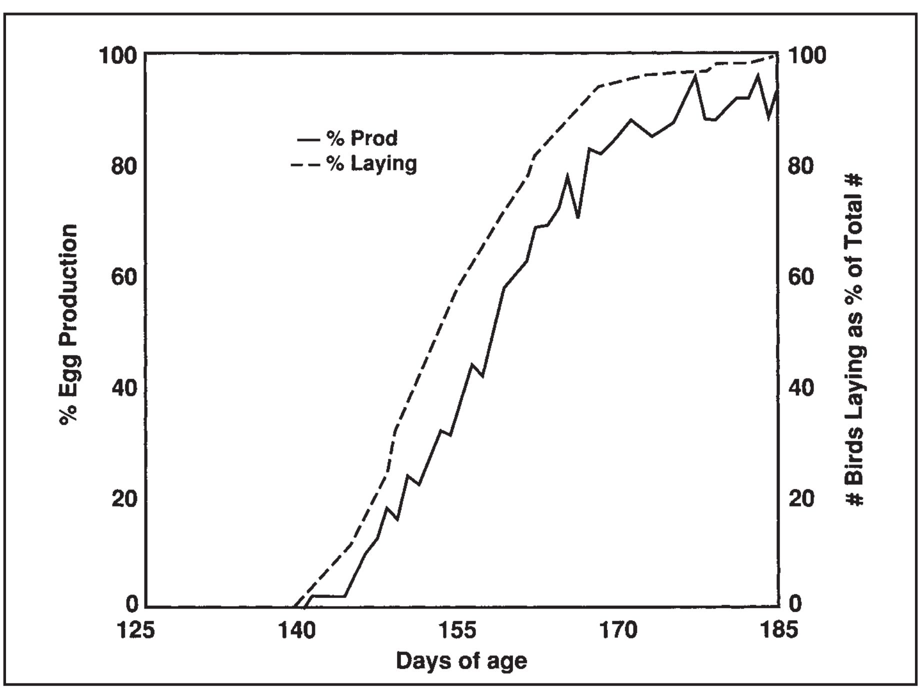
Fig. 4.1 Egg production (18-66 weeks) in response to daily intakes of energy and protein.



Many problems associated with marginal nutrient intake of young layers can most often be overcome by ensuring optimum body weight and appetite of young laying pullets. Unfortunately, mean weight of the flock at this age, is too often considered independently of flock uniformity. Pullets may be of 'mean' body weight, yet be quite variable in weight, and often outside the accepted range of 85% of the flock being within ± 10% of mean weight. The major problem with a non-uniform flock is variability in age at first egg, and so variability in feed intake. If diets are tailored to feed intake, then late maturing smaller birds (with small appetites) will likely be underfed. Conversely heavier, early maturing pullets with increased appetites may be overfed at this time. The consequence is often a delayed peak, and reduced overall egg production.

An argument against being overly concerned about uniformity, is that birds will adjust their intake according to nutrient (energy) needs, and so early maturing birds will eat more, and late maturing birds less, during the early phases of production. However, if birds are given diets formulated based on feed intake, this can lead to problems, the most serious of which is overfeeding of the larger early maturing bird. Another confounding factor is that as birds mature within a flock, the percent production realized on a daily basis does not reflect the number of birds laying at that time. As shown in Figure 4.2, the proportion of laying birds always exceeds the percent production calculated and this difference is most pronounced in early production. For example, at about 40% production, there are, in fact, around 70% of the birds mature and requiring proportionally more nutrients than suggested by egg production alone.

Fig. 4.2 Comparison of number of birds producing eggs and actual egg production



4.3 Problems with heat distress

The majority of the world's laying hens are kept in areas where heat stress is likely to be a major management factor at some stage during the production cycle. The major problem relates to birds not consuming enough feed at this time, although there are also some subtle changes in the bird's metabolism that affect both production and shell quality. While all types of poultry thrive in warm environments during the first few weeks of life, normal growth and development of older birds is often adversely affected. Obviously, the bird's requirements for supplemental heat declines with age, because insulating feathers quickly develop and surface area, in relation to body size, is reduced. Heat stress is often used to describe bird status in hot environments, although it is obvious that more than just environmental temperature *per se* is involved. Because birds must use evaporative cooling (as panting) in order to lose heat at high temperatures, humidity of inhaled air becomes critical. High temperature and humidity combined are much more stressful to birds than is high temperature alone. Other environmental factors such as air speed and air movement are also important. It is also becoming clear that adaptation to heat stress can markedly influenced bird response. For example, laying birds can tolerate constant environmental temperatures of 35˚C and perform reasonably well. On the other hand, most birds are stressed at 35˚C when fluctuating day/night temperatures are involved. In the following discussion, it is assumed that fluctuating conditions exist, since these are more common and certainly more stressful to the bird.

Figure 4.3 shows the bird's generalized response to variable temperature and humidity. Regardless of housing system, environmental conditions of > 32˚C and > 50% RH are likely to cause some degree of heat distress. Table 4.12 shows typical layer response to high environmental temperatures.

Table 4.12 Performance of brown egg layers at 18˚C vs. 30˚C

	Feed intake (g/b/d)	*Egg production (%)*	*Egg weight (g)*	*Shell (% of egg)*	
				40 wk	***60 wk***
18˚C	*131*	*91.2*	*60.9*	*9.5*	*9.1*
30˚C	*108*	*83.6*	*57.2*	*9.0*	*8.6*

Adapted from Chen and Balnave (2001)

Fig. 4.3 Generalized bird response to temperature and humidity.

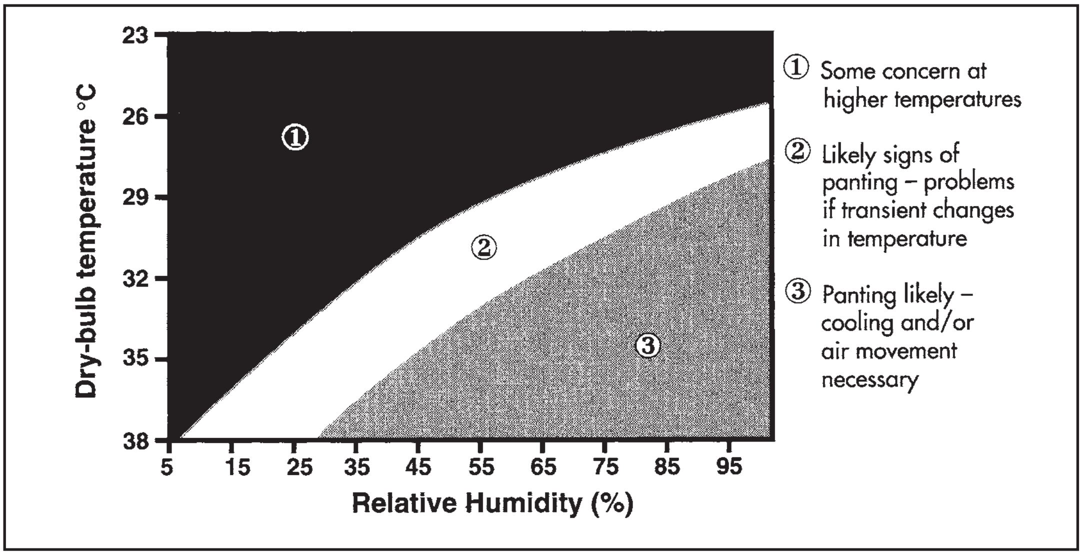
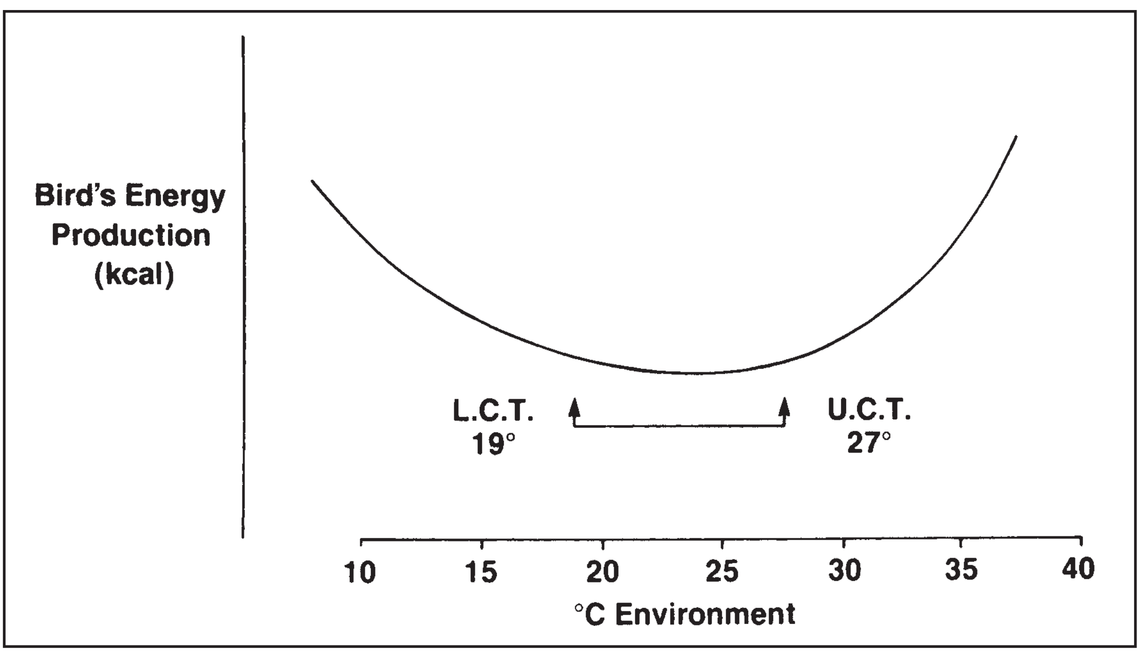


Fig. 4.4 Environmental temperature and body heat production.



The main concern under hot weather conditions is the layer's ability to consume feed. As poultry house temperature increases, then less heat is required to maintain body temperature and the birds consume less feed. In this situation, 'environmental' energy is replacing feed energy and is economical. However, the relationship between body heat production and house temperature is not linear, since at a certain critical temperature, the bird's energy demands are increased in order to initiate body cooling mechanisms. The following factors should be con-

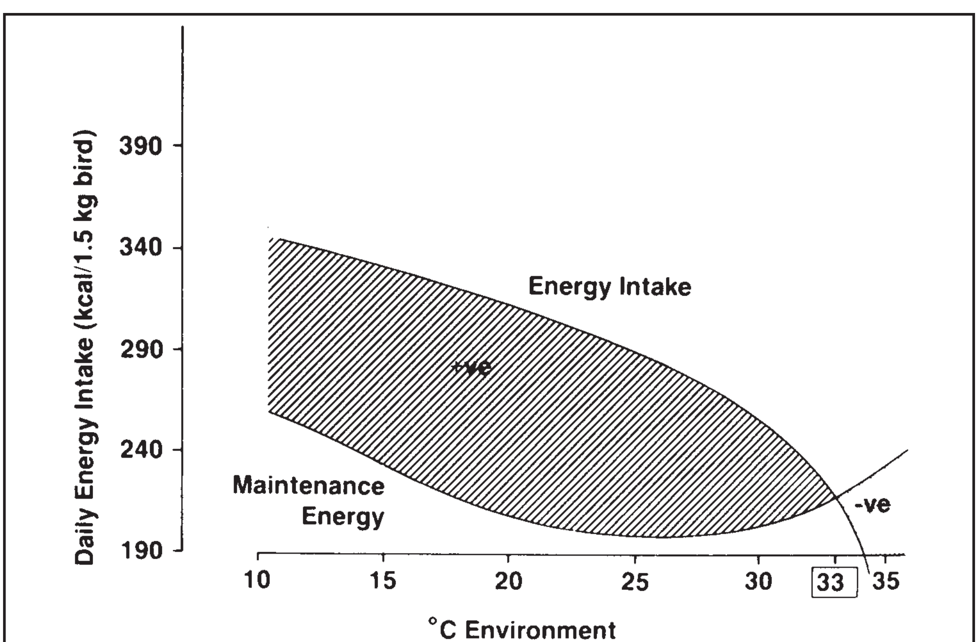
sidered in attempting to accommodate the bird's reaction to heat stress:

a) Bird's response to heat stress –

Figure 4.4 is a schematic representation of a heat stress effect. Minimal body heat production (and hence the most efficient situation) is seen at around 23˚C. Below this temperature, (lower critical temperature) birds generally have to generate more body heat in order to keep warm. However, there is only a narrow range of temperature (19-27˚C) over which heat production is minimal. Above 27˚C birds start to use more energy in an attempt to stay cool. For example, at 27˚C, birds will start to dilate certain blood vessels in order to get more blood to the comb, wattles, feet etc. in an attempt to increase cooling capacity. More easily observed is the characteristic panting and wing drooping that occurs at slightly higher temperatures. These activities at high environmental temperatures mean that the bird has an increased, rather than decreased, demand for energy. Unfortunately, the situation is not as clear cut as depicted in Figure 4.4 and this is likely the reason behind the variability seen in flock response to various environmental conditions. Rather than lower and upper critical temperature being rigidly fixed under all conditions, heat production is likely to fluctuate in response to a number of very practical on-farm conditions.

Variation in response can be caused by such factors as (a) increased feed intake; (b) degree of feathering or; (c) increased bird activity. Such potential variability in bird response should be taken into account when interpreting the quantitative data discussed in Figures 4.5 and 4.6. The whole picture is further confused by the normal energy intake pattern of the bird (Figure 4.5). The upper line of Figure 4.5 represents energy intake for a 1.5 kg white egg layer. As environmental temperature increases, energy intake declines. However, above 27 – 28˚C the decline becomes quite dramatic since the bird is changing its metabolic

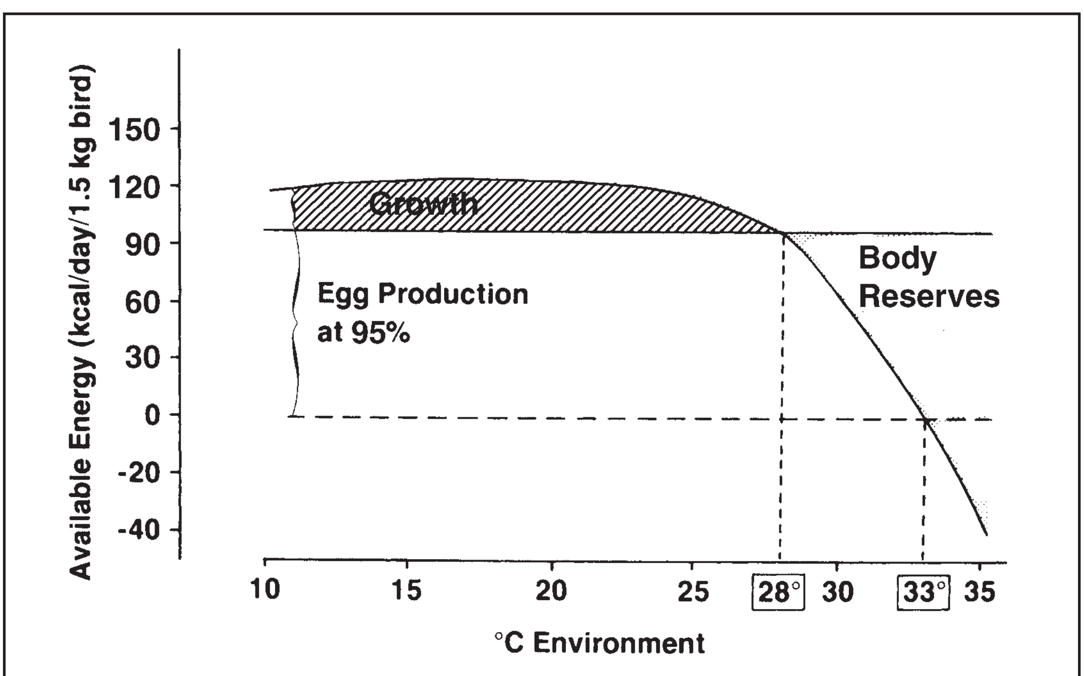
Fig. 4.5 Environmental temperature and energy balance.



processes in response to the heat load, and actions such as panting, etc. adversely influence the feeding mechanisms in the brain and also reduce the time available for feeding. The shaded area between the lines in Figure 4.5 represents the energy available for production. At around 28˚C the energy available for production is dramatically reduced and around 33˚C actually becomes negative. If energy available for production is plotted against temperature, the energy potential for egg production is clearly evident (Figure 4.6).

A 60 g egg contains around 80 kcal gross energy, and this requires around 100 kcal ME of dietary input, assuming 80% efficiency of utilization of this ingested energy. If the bird is at 95% production, then there is a need for 95 kcal ME/d to sustain peak egg output. There will also be need for 15 – 25 kcal ME for daily growth of this young pullet, for a total need of around 115 kcal ME/d for productive purposes. At moderate environmental temperatures, such energy yield is readily obtained from the feed, since with average intakes of 270 – 275 kcal ME/bird/day, there is adequate energy for production and maintenance. However, as feed intake declines, available energy will decline. Although maintenance energy needs are less at higher temperatures, the non-linear relationship (Figure 4.5) causes problems of energy sufficiency at around 28˚C (Figure 4.6). Above this temperature, if production and growth are to be sustained, the birds will have to use body energy reserves in order to balance energy demands. There are obvious limits to such fat reserves, especially with young pullets, and so it is unlikely that the pullet can sustain 95% egg production for too long a period under these conditions.

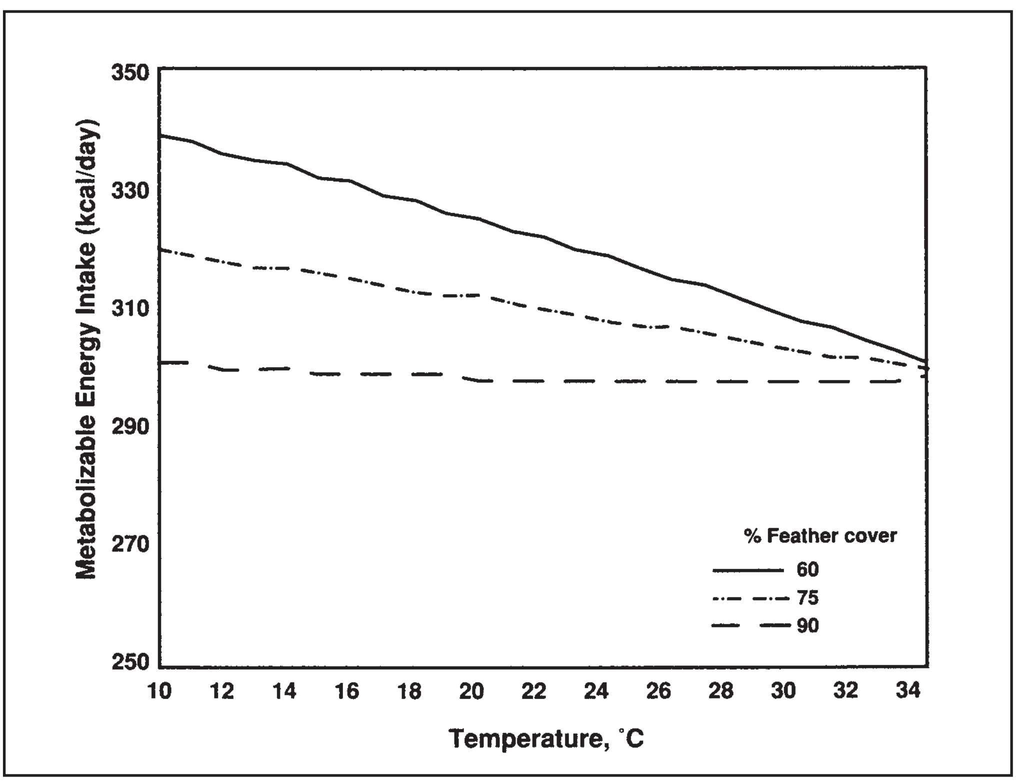
Fig. 4.6 Environmental temperature and energy balance.



The bird has no option but to reduce egg output in order to sustain energy needs for maintenance. Under actual farm conditions, the temperatures at which critical changes occur (28˚C and 33˚C in Figure 4.6) will vary, especially with acclimatization to temperature, but events will likely be initiated within ± 2˚C of the values shown in Figure 4.6.

A major factor affecting the bird's energy intake in response to environmental temperature is feather cover, which represents insulating capacity for the bird. Coon and co-workers have developed equations that take into account degree of feathering, although this assumes a linear trend across all temperatures. Figure 4.7 uses these equations to predict energy intake up to around 25˚C, at which time it is assumed that a degree of heat distress will occur and this will be most prevalent for the well-feathered bird. The response after 26˚C assumes increased energy need, as shown in Figure 4.5. The actual situation may be more complex than this in tropical regions where birds are held in open-sided houses and where there is the expectation of cool nighttime temperatures.

Fig. 4.7 ME intake of layers with 60, 75 or 90% feather cover at 10-34 ˚C



Adapted from (Peguri and Coon, 1995)

b) Maintaining energy balance –

The key to sustaining production in hot climates is to maintain a positive energy balance.

i) Changing diet energy level - It is well known that birds consume less feed as the energy level of the feed increases. This is because the bird attempts to maintain a given energy intake each day. However, the mechanism is by no means perfect and as energy level is increased, the actual decline in feed intake is often imperfectly regulated, leading to 'overconsumption' of energy. As environmental temperature increases, the mechanism seems even less perfect and so increasing diet energy level is often considered in an attempt to stimulate energy intake. Payne (1967) showed this classical effect with brown egg layers fed 2860 to 3450 kcal ME/kg at 18˚C or 30˚C (Table 4.13). At 18˚C there is fairly good adjustment by the bird in that feed intake is sequentially reduced as energy level increases and energy intake is maintained constant. At high temperatures, birds adjust feed intake less perfectly and 'overconsumption' of energy occurs. It is not suggested that these extremes of diet energy be used commercially, rather that energy intake will be maximized with as high a diet energy level as is possible. In order to increase diet energy level, the use of supplemental fat should be considered. Dietary fat has the advantage of increasing palatability and also reducing the amount of heat increment that is produced during its utilization for production.

ii) Physical stimulation of feeding activity –
Various methods can be used to stimulate feed intake. Feeding more times each day usually encourages feeding activity. Feeding at cooler times of the day, if possible, is also a useful method of increasing the bird's nutrient intake. If artificial lights are used, it may be useful, under extreme environmental conditions, to consider a so-called midnight feeding when temperature will hopefully be lower and birds are more inclined to eat. When heat stress is extreme, making the diet more palatable may be advantageous. Such practices as pouring vegetable oil, molasses, or even water directly onto the feed in the troughs will encourage intake. Whenever high levels of fat are used in a diet, or used as a top dressing as described here, care must be taken to ensure that rancidity does not occur. This can best be achiev -ed by insisting on the incorporation of quality

Table 4.13 Effect of diet energy level on metabolizable energy intake

	18˚C		*30˚C*	
Diet energy (kcal ME/kg)	*Feed/day (g)*	*Energy/day (kcal)*	*Feed/day (g)*	*Energy/day (kcal)*
2860	*127*	*363*	*107*	*306*
3060	*118*	*360*	*104*	*320*
3250	*112*	*364*	*102*	*330*
3450	*106*	*365*	*101*	*350*

Adapted from Payne (1967)

antioxidants in the feed and that feed not be allowed to 'cake' in tanks, augers or troughs. Freshness of feed becomes critical under these conditions.

Diet texture can also be used to advantage. Crumbles or large particle size mash feed tend to stimulate intake while a sudden change from large to small feed particles also has a transitory effect on stimulating intake. It is interesting to observe that a sudden change from small to large crumbles seems to have a negative effect on intake (Table 4.14).

Midnight feeding is often used when birds are subjected to heat stress conditions. Light for 1 – 2 hrs has at least a transitory effect on increasing feed intake (1 – 3 %) and often has a long-term effect. With moderately high temperatures it may only be necessary to provide lighting, while with extreme hot weather it is advisable to also run the feeder lines during this 1 hour time period. An interesting observation with midnight feeding is the bird's dramatic increase in water intake (see Figure 4.8). Layers will eat more feed in hot weather conditions, if the 'effective temperature' is reduced. This is sometimes achieved with evaporative cooling depending upon inherent levels of humidity. A less costly, but very effective system of stimulating intake, is to increase air movement. Body temperature of the bird is close to 41˚C, and the air within the 1-2 mm boundary layer around the bird will be close to this temperature. By increasing air speed, the boundary layer is disrupted, so aiding in cooling the bird. Table 4.15 shows the effect of air movement on the cooling effect on the bird and the expected increase in feed intake.

iii) Body fat reserves – Adequacy of pullet rearing programs become most critical when birds are to be subjected to hot weather in the time up to peak egg mass production. As detailed in Figure 4.6, the layer may well have to rely on its body energy reserves as a supplement to its diminished energy intake from the feed. Rearing programs designed to maximize growth have been discussed previously. The heavier the bird at maturity, the larger the body weight throughout lay, and hence the larger the potential energy reserve and also the greater the inherent feed intake (Table 4.16)

It is not suggested that extremely fat pullets are desirable, but it is obvious that birds of optimum weight with a reasonable fat reserve are best suited to heat stress situations. Pullets that are subjected to heat stress and have less 'available' energy than that required to sustain production, have no recourse but to reduce egg mass output in terms of egg weight and/or egg numbers, since maintenance energy needs are always a priority.

Table 4.14 Effect of sudden change in feed particle size on feed intake 5-7d following this change

	Crumb size		
	Regular	***Regular to small (<2.4 mm)***	***Regular to large (> 2.4 mm)***
Feed (g/bird/day)	*112[b]*	*124[a]*	*81[c]*

Table 4.15 Cooling effect of air movement (wind chill) and expected increase in feed intake of layers maintained at 30°C

Air movement (meters/second)	*Cooling effect (˚C)*	*Expected increase in feed intake (g/b/d)*
0.5	1	Up to 1 g
0.75	2	1 – 2 g
1.0	3	2 - 3 g
1.25	4	3 - 4 g
1.50	5	4 – 5 g
1.75	6	5 – 6 g

Table 4.16 Leghorn pullet size and energy intake

Body Weight (g)		*Daily energy consumption*
18 wk	*24 wk*	*18-25 wks (kcal)*
1100	1400	247
1200	1500	254
1300	1600	263
1400	1700	273

c) Protein and amino acids –

It is tempting to increase the crude protein level of diets during heat stress conditions. This has been done on the basis of reduced feed intake, and hence protein levels have been adjusted upwards in an attempt to maintain intakes of around 19 g crude protein/bird/day. It is now realized that such adjustments may be harmful. When any nutrient is metabolized in the body, the processes are not 100% efficient and so some heat is produced. Unfortunately, protein is the most inefficiently utilized nutrient in this regard and so, proportionately more heat is evolved during its metabolism compared to that of fat and carbohydrates. The last thing that a heat stressed bird needs is additional waste heat being generated in the body. This extra heat production may well overload heat dissipation mechanisms (panting, blood circulation). We are therefore faced with a difficult problem of attempting to maintain 'protein' intake in situations of reduced feed intake, when crude protein *per se* may be detrimental. The answer to the problem is not to increase crude protein, but rather to increase the levels of essential amino acids. By feeding synthetic amino acids, we can therefore maintain the intake of these essential nutrients without the need to catabolize excess crude protein (nitrogen). General recommendations are, therefore, to increase the use of synthetic methionine and lysine and perhaps threonine to maintain daily intakes of approximately 420, 820 and 660 mg respectively for birds around peak egg production.

d) Minerals and vitamins –

Calcium level should be adjusted according to the anticipated reduction in feed intake, so that birds consume at least 4.2 g per day. Under extreme conditions, this may be difficult since,

as previously indicated, high energy diets are also desirable and these are difficult to achieve with the increased use of limestone or oyster shell. Table 4.17 shows the diet specifications needed to maintain intakes of Ca, P, and vitamin D_3, all of which are critical for eggshell quality.

Table 4.17 Diet nutrient levels needed to maintain constant intake of these nutrients at varying levels of feed intake

Feed intake (g/d)	*Av P (%)*	*Ca (%)*	*Vit. D_3 (IU/kg)*
80	*0.52*	*5.3*	*4125*
90	*0.47*	*4.7*	*3660*
100	*0.42*	*4.2*	*3300*
110	*0.38*	*3.8*	*3000*

Because it is also necessary to increase the energy level of the diet when feed intake is low, then it is counterproductive to add high levels of limestone and phosphates, which effectively dilute the feed of all nutrients other than Ca and phosphorus. The problem of potential calcium deficiency is most often met by top dressing feed with oystershell or large particle limestone. The deficit of vitamin D_3 is best met with use of D_3 supplements in the drinking water rather than formulation of a new premix.

There seems to be some benefit to adding sodium bicarbonate to the diet or drinking water. However, this must be done with care so as not to impose too high a load of sodium on the bird, and so salt levels may have to be altered. This should be done with great caution, taking into account sodium intake from the drinking water, which can be quite high during heat stress conditions. In most situations, there will be no negative effects from replacing 30% of supplemental salt with sodium bicarbonate on a kg for kg basis. There is also an indication of beneficial effects of increasing the potassium levels in the diet, although again, this must be accomplished only after careful calculation, since higher levels can be detrimental to electrolyte balance. While few reports indicate any improvement in adding supplemental B vitamins during heat stress, there are variable reports of the beneficial effects with the fat soluble vitamins. Although not always conclusive, increasing the levels of vitamins A, D_3 and E have all been shown to be advantageous under certain conditions. While vitamin C (ascorbic acid) is not usually considered in poultry diets, there is evidence to support its use during hot weather conditions. Under most circumstances, birds are able to synthesize their needs of vitamin C but under heat stress, such production may be inadequate and/or impaired. Adding up to 250 mg vitamin C/kg diet has proven beneficial for layers in terms of maintaining production when temperatures exceed 28ºC.

e) Electrolyte balance –

As environmental temperature increases, birds increase their respiration rate in an attempt to increase evaporative cooling. As birds pant, they tend to lose proportionally more CO_2 and so changes in acid-base balance can quickly develop. With mild to severe alkalosis, blood pH may change from 7.2 through 7.5 to 7.7 in extreme situations. This change in blood pH, together with loss of bicarbonate ions can influence eggshell quality and general bird health and metabolism. Under such heat stress conditions, it is the availability of bicarbonate *per se* which seems to be the major factor influencing eggshell synthesis and in turn, this is governed by acid-base balance, kidney function and respiration rate.

Shell formation normally induces a renal acidosis related to the resorption of filtered bicarbonate. At the same time, shell secretion induces a metabolic acidosis because the formation

of insoluble $CaCO_3$ from HCO_3 and Ca^{2+} involves the liberation of H^- ions. Such H^- release would induce very acidic and physiologically destructive conditions, and be necessarily balanced by the bicarbonate buffer system in the fluid of the uterus. While a mild metabolic acidosis is therefore normal during shell synthesis, a more severe situation leads to reduced shell production because of intense competition for HCO_3 as a buffer rather than for shell formation. A severe metabolic acidosis can be induced by feeding products such as NH_4Cl, and this results in reduced shell strength. In this scenario, it is likely that NH_4 rather than Cl^- is problematic because formation of urea in the liver (from NH_4) needs to be buffered with HCO_3 ions, creating added competition for shell formation. Conversely, feeding sodium bicarbonate, especially when Cl^- levels are minimized, may well improve shell thickness. Under commercial conditions, the need to produce base excess in order to buffer any diet electrolytes must be avoided. Likewise it is important that birds not be subjected to severe respiratory excess, as occurs at high temperatures, because this lowers blood bicarbonate levels and in extreme cases, causes a metabolic acidosis. Under practical conditions, replacement of part (30-35%) of the supplemental dietary NaCl with $NaHCO_3$ may be beneficial for shell production.

Acclimatization to heat stress is a confounding factor because short-term (1-2 d) acute conditions are more problematic to the bird. For example, pullets grown to 31 weeks under constant 35 vs 21ºC conditions exhibit little difference in pattern of electrolytes. If birds are allowed to acclimatize to high environmental temperatures there is little correlation between plasma electrolytes and shell quality. Temporary acute heat stress and cyclic temperature conditions are undoubtedly the most stressful to the bird.

Severe electrolyte imbalance can be prevented by considering the ratio of cation:anion in diet formulations. However, it must be accepted that the diet is only one factor influencing potential imbalance, and so, general bird management and welfare also become of prime importance. Electrolyte balance is usually a consideration of Na+K-Cl in the diet, and under most dietary situations, this seems a reasonable simplification. Electrolyte balance is usually expressed in terms of mEq of the various electrolytes, and for an individual electrolyte this is calculated as Mwt ÷ 1,000. This unit is used on the basis that most minerals are present at a relatively low level in feeds. As an example calculation, the mEq for a diet containing 0.17% Na, 0.80% K and 0.22% Cl can be calculated as follows:

Sodium	Mwt = 23.0, ∴ Eq = 23g/kg, ∴ mEq = 23mg/kg Diet contains 0.17% Na = 1,700 mg/kg = 1700/23 mEq = 73.9 mEq
Potassium	Mwt = 39.1, ∴ Eq = 39.1g/kg, ∴ mEq = 39.1mg/kg Diet contains 0.80% K = 8,000 mg/kg = 8,000 /39.1 mEq = 204.6 mEq
Chloride	Mwt = 35.5, ∴ Eq = 35.5g/kg, ∴ mEq = 35.5mg/kg Diet contains 0.22% Cl = 2,200 mg/kg, = 2,200/35.5 mEq = 62.0 mEq

∴ overall diet balance becomes Na + K – Cl = 73.9 + 204.6 – 62.0 = 216.5 mEq.

Table 4.18 Electrolyte content of feed ingredients

INGREDIENT	*Na*	*K*	*Cl*	*Na+K-Cl (mEq)*
Corn	*0.05*	*0.38*	*0.04*	*108*
Wheat	*0.09*	*0.52*	*0.08*	*150*
Milo	*0.04*	*0.34*	*0.08*	*82*
Soybean meal	*0.05*	*2.61*	*0.05*	*675*
Canola meal	*0.09*	*1.47*	*0.05*	*400*
Meat meal	*0.55*	*1.23*	*0.90*	*300*
Fish meal	*0.47*	*0.72*	*0.55*	*230*
Cottonseed meal	*0.05*	*1.20*	*0.03*	*320*

A balance of around 250 mEq/kg is usual, and so for this diet, there needs to be either an increase in Na or K level of the diet, or a decrease in Cl level.

Under practical conditions, electrolyte balance seems to be more problematic when chloride levels are high. On the other hand, use of $NaHCO_3$ to replace NaCl, as is sometimes recommended during heat stress, can lead to a deficiency of chloride. Changes in diet electrolyte balance most commonly occur when there is a major change in ingredient usage and especially when animal protein sources replace soybean meal and vice versa. Table 4.18 outlines electrolyte balance of some major feed ingredients.

Within the cereals, Na+K-Cl for milo is low, while wheat is high relative to corn. Major differences occur in the protein-rich ingredients, and relative to soy, all sources are low in electrolyte balance. As shown in Table 4.18, this situation develops due to the very high potassium content of soybean meal. Careful consideration to electrolyte balance must therefore be given when changes are made in protein sources used in formulation. For example, the overall balance for a diet containing 60% milo and 25% soy is 210 mEq/kg, while for a diet containing 75% milo and 10% fish meal, the balance is only 75 mEq/kg. The milo-fish diet would need to be supplemented with $NaHCO_3$.

Assuming that heat stress cannot be tempered by normal management techniques, then electrolyte manipulation of the diet may be beneficial. However, the technique should be different for immature birds compared to egg layers. With layers, there is a need to maintain the bicarbonate buffer system as it influences eggshell quality. As such, diet or water treatment with sodium bicarbonate may be beneficial, again emphasizing the necessity to meet minimum chloride requirements. On the other hand, treatment of respiratory alkalosis in layers with acidifiers such as NH_4Cl, while relieving respiratory distress, may well result in reduced shell quality. For immature pullets, treatment with electrolytes is often beneficial and there is less need for caution related to bicarbonate buffering. Up to 0.3% dietary NH_4Cl may improve the growth rate of heat stressed birds, although it is not clear if any effect is via electrolyte balance/blood pH or simply via the indirect effect of stimulating water intake. Under commercial conditions, adding salt to the drinking water of young birds has been reported to alleviate bird distress and to stimulate growth.

f) Water –

A nutritional factor often overlooked during heat stress is the metabolism of water. It is well known that birds in hot environments drink more water, yet this has not been capitalized upon to any degree. Table 4.19 shows the water balance of layers held at 22˚C or 35˚C.

Table 4.19 Water balance of layers at 22ºC or 35ºC (ml/bird/day)

	22˚C	*35˚C*
Water intake	210	350
Manure water	85	150
Egg water	50	50
Respiration water	75	150

Layers will drink at least 50% more water at 35 vs. 22˚C. If such adaptation is not seen, then it likely relates to birds not being able to consume sufficient quantities of water at times of peak need. Figure 4.8 shows the daily pattern of water intake of layers when lights are on from 6:30 a.m. to 6:30 p.m. There is a doubling of water intake in the last 3 hours of the day, compared to all previous times, and so the water system must be able to accommodate this demand, especially in hot weather conditions.

Since water intake is often increased at times when feed intake is decreased, it would be logical to try and provide limiting nutrients in the water. However, this concept has met with only limited success, possibly related to change in 'taste' of the water and/or the nutrients stimulating bacterial growth in the water lines. However there are always positive results seen when the drinking water is cooled. Feed intake can be stimulated as much as 10% by cooling the water 5 to 8˚C when environmental temperature is around 30 – 32˚C. Although this management practice is relatively easy to achieve under experimental conditions, it is a much more complex engineering problem with large commercial flocks.

g) Effect of physical diet change –

Discussion to date has centered on the potential of diet manipulation to alleviate heat stress. However, diet change *per se* may be detrimental under certain conditions. It seems that when the bird is confronted with an acute heat stress situation, diet change may impose another stress, which merely accentuates any metabolic imbalance. For example, it was recently reported that a diet change brought about by adding fat caused an immediate rise in body temperature for up to 4 d which can be disastrous to the bird and cause death. At the same time, the diet change had the desirable effect of stimulating energy intake. For this reason, it is suggested that under extreme heat stress conditions of 36 – 40˚C, that no diet change be implemented, since it could lead to death from heat prostration.

Fig. 4.8 Daily pattern of relative water intake. Lights on @ 6:30am for 12 hrs/d

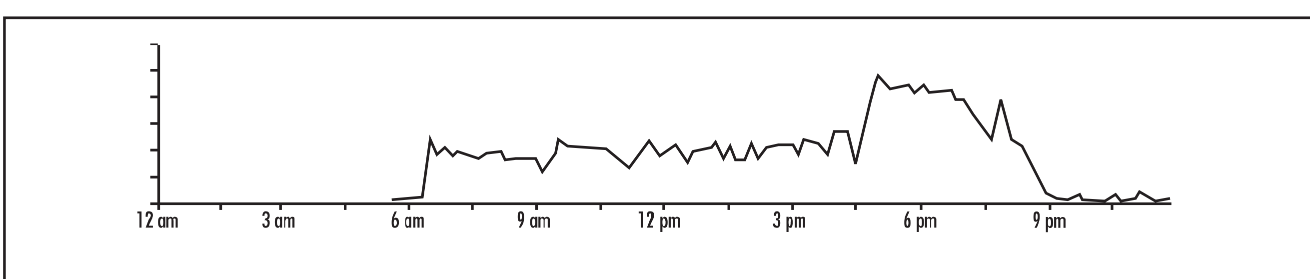


Table 4.20 Effect of diet change on layer performance during heat stress

		@ 21 wks of age			@ 33 wks of age		
	Diet type	Egg prod. (%)	Feed intake (g)	Shell deformation (µm)	Egg prod. (%)	Feed intake (g)	Shell deformation (µm)
Pre-test 7 d (18°C)	Control	82	86	21	92	101	24
Stress 3 d (35°C)	Control	92	64[a]	22[b]	71	50[a]	35[b]
	High CP	90	36[c]	24[a]	56	20[b]	41[ab]
	High Energy	94	40[c]	23[ab]	60	27[b]	46[a]
	High Density	96	53[b]	24[a]	67	28[b]	37[b]
Post-stress 4 d (18°C)	Control	84[a]	76[a]	26[c]	77[a]	84[a]	30[b]
	High CP	39[c]	24[b]	35[ab]	45[b]	61[bc]	41[a]
	High Energy	56[b]	33[b]	41[a]	64[a]	57[c]	42[a]
	High Density	69[ab]	76[a]	31[bc]	67[a]	73[ab]	29[b]

[a-c] *means followed by different letters are significantly different*

Under these conditions, it would be useful to be able to prejudge the rise in environmental temperature and make the diet change earlier, when the bird is under 'moderately' stressful conditions (28 – 35˚C). However, even with short-term heat stress situations, it may be inadvisable to change the diet (Table 4.20).

In these studies, birds were fed a control ration for 7 d at an environmental temperature of 18˚C. A heat stress of 35˚C was suddenly imposed, and birds offered the same control diet, or diets high in energy, protein or all nutrients (termed high density). Feed intake was depressed almost immediately in response to heat stress, although changes in egg production and shell quality were not seen until after the 3 d stress period. However, during this post-stress period, birds showed a dramatic loss in egg numbers and shell quality. There was no instance of diet change alleviating the effects of heat stress, and in most situations, production deteriorated. Under such conditions of short-term heat stress, it is suggested that sudden diet change merely imposed an additional stress and was not beneficial to the bird.

h) Summary of nutritional management during heat

1. Never place underweight pullets in the laying house. They will always remain small with low feed intake and have little body fat reserve to sustain energy balance through the period of peak egg mass production.

2. Increase the energy level of the diet with a minimum of 2850 kcal ME/kg, ideally by incorporation of fats or oils. Limit the level of crude fiber.

3. Reduce crude protein (17% CP maximum) while maintaining daily intakes of methionine (420 mg), lysine (820 mg) and threonine (660 mg).

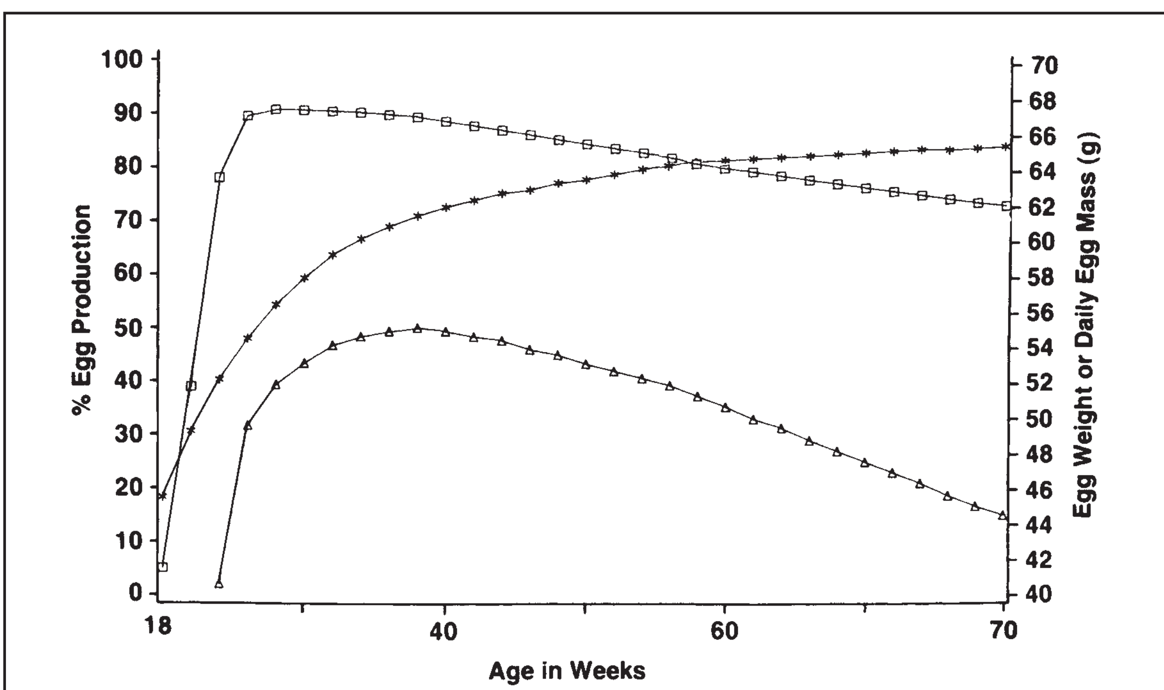
4. Increase mineral-vitamin premix in accordance with anticipated change in feed intake. Maintain daily intakes of calcium (4.2 g) and available phosphorus (400 mg).

5. Where shell quality is a problem, consider the incorporation of sodium bicarbonate. At this time, monitor total sodium intake, and ensure adequate chloride levels in the diet.
6. Use supplemental vitamin C at 250 mg /kg.
7. Increase the number of feedings per day and try to feed at cooler times of the day.
8. Keep drinking water as cool as possible.
9. Use crumbled feed or large particle mash feed if available.
10. Do not make any diet change when sudden short-term (3 – 5 d) heat stress occurs.

4.4 Phase Feeding

Phase feeding refers essentially to reductions in the protein and amino acid level of the diet as the bird progresses through a laying cycle. The concept of phase feeding is based on the fact that as birds get older, their feed intake increases, while egg mass output decreases. For this reason, it should be economical to reduce the nutrient concentration of the diet. At this time, it is pertinent to consider a conventional egg production curve of a layer, and superimpose both egg weight and daily egg mass output (Figure 4.9).

Fig. 4.9 Bird age: egg production, egg weight and egg mass.



If nutrient density is to be reduced, this should not occur immediately after peak egg numbers, but rather after peak egg mass has been achieved. The two reasons for reducing the level of dietary protein and amino acids during the latter stages of egg production are first, to reduce feed costs and second, to reduce egg size. The advantages of the first point are readily apparent if protein costs are high, but the advantages of the second point are not so easily defined and will vary depending upon the egg pricing. When a producer is being paid a premium for extra large and jumbo eggs, there is no advantage to using a phase feeding program unless eggshell quality is a problem.

It is difficult to give specific recommendations regarding any decrease in dietary protein or amino acid level that can be made to temper egg size without also decreasing the level of production. The appropriate reduction in protein level will depend on the season of the year (effect of temperature on feed consumption, age and production of the bird, and energy level of the diet). Hence, it is necessary that every flock be considered on an individual basis before a decision is made to reduce the level of dietary protein. As a guide, it is recommended that protein intake be reduced from 19 to 18 g/day after the birds have dropped to 90% production, and to 15-16 g/day after they have dropped to 80% production. With an average feed intake of 95 g/day, this would be equivalent to diets containing 20, 19 and 16% protein. It must be stressed that these values should be used only as a guide, and after all other factors have been properly considered. If a reduction in the level of protein is made and egg production drops, then the decrease in nutrient intake has been too severe and it should be immediately increased. If, on the other hand, production is held constant and egg size is not reduced, then the decrease in protein or amino acid intake has not been severe enough and it can be reduced still further. The amino acid to be considered in this exercise is methionine, since this is the amino acid that has the greatest effect on egg size. As for the situation with protein, too large a single step reduction in methionine will likely lead to loss in egg production and possibly an increase in feed intake. A one-time reduction in diet methionine of 20% has been reported to reduce egg size by 3% with concommitant loss in egg production of 8%.

Phase feeding of phosphorus has also been recommended as a method of halting the decline in shell quality invariably seen with older birds. Using this technique, available phosphorus levels may be reduced from approximately 0.42 – 0.46% at peak production to slightly less than 0.3% at end of lay. Table 4.21 shows an example of

Table 4.21 Phase feeding of major nutrients after peak egg mass, assuming constant daily feed intake at 100 g

Bird characteristics		*Diet levels (%)*			
Age (wks)	*Egg production (%)*	*Crude protein*	*Methionine*	*Calcium*	*Av. phosphorus*
<35	*93*	*19.0*	*0.41*	*4.2*	*0.44*
45	*90*	*18.0*	*0.38*	*4.3*	*0.41*
55	*85*	*17.0*	*0.36*	*4.4*	*0.36*
70	*80*	*16.0*	*0.34*	*4.5*	*0.32*

phase feeding of protein, methionine and phosphorus, related to controlling egg size, optimizing shell quality and minimizing feed costs.

A major criticism of phase feeding is that birds do not actually lay 'percentages' of an egg. For example, if a flock of birds is producing at 85% production does this mean that 100% of the flock is laying at 85% or is 85% of the flock laying at 100% production. If a bird lays an egg on a specific day, it can be argued that its production is 100% for that day, and so its nutrient requirements are the same regardless of the age of bird. Alternatively, it can be argued that many of the nutrients in an egg, and especially the yolk, accumulate over a number of days, and so this concept of 100% production, regardless of age, is misleading.

Advocates of phase feeding indicate that birds can be successfully managed by reducing protein/amino acid contents of the diet – others suggest that nutrient specifications are too high to start with initially, and that phase feeding merely accomplishes normalization of diet in relation to requirement. The bottom line is that environmental and management conditions vary from flock to flock, and certainly from season to season within a flock. For this reason, the basis of phase feeding must be an accurate assessment of the nutrient intake relative to requirement for production, growth and maintenance.

4.5 Formulation changes and feed texture

With diets formulated to least cost ingredient input, it is often necessary to change ingredient concentrations, and depending upon economic circumstances, the computer invariably 'asks' for major changes at certain times. In these situations, nutritionists are often reluctant to make major ingredient substitutions in consecutive diets, on the basis that such change may adversely affect feed intake and hence product. In a recent study, birds were fed a range of diets over a 12-month cycle, with the situation of least cost where major changes in ingredient use occurred in most months. Control birds were fed least cost formulated diets, although in this situation major ingredient changes from month to month were not allowed, rather these changes occurred more gradually as occurs commercially. Birds responded reasonably to these changes and no major adverse effects were seen. However, a slight improvement in egg production and egg size with a conventional least cost system, where diet changes were tempered to prevent drastic swings in diet composition, somewhat negated the savings in feed costs seen with absolute least cost. The economic situation in terms of egg return minus feed cost was in favor of conventional least cost, mainly due to a doubling of the mortality rate with the major swings in diet composition. It seems that while the absolute least cost diets are initially attractive in reducing feed cost, they offer little overall economic advantage and generally pose an additional economic risk.

The texture of diets for laying hens is perhaps subject to more variability than for any other class of poultry. In some countries, very fine mashes are used, whereas crumbles are used in other areas. There is little doubt that any type of feed texture can be made to work physically, although bird response is not always the same. Our research data suggests that regardless of nutrient profile, layers prefer large particles of feed. When layers were offered a crumbled diet, they show a marked preference for the largest size particles available. Smaller particles of feed only

start to disappear later within a 24 h period, when all the large particles have been eaten. In this study, there was no disappearance of very fine particles <0.6 mm, although this result may be confounded with the break down of large particles. Feed intake increased when birds were suddenly presented with feed of small particle size, and intake temporarily declined when birds were offered only large size particles. A criticism of mash diets is that they tend to separate out when used in long runs of feed trough, and especially where continous chain feeders are used. From a survey of commercial flocks in Ontario, we found comparable physical separation of feed with both mash and crumbles (Table 4.22).

In this study, feed samples were taken directly from the feed tank and then at points progressively further from the initial point of distribution within the feed trough. Particle and nutrient separation were seen at all farms (Table 4.22). With crumbled feed, particle size was dramatically reduced as feed traveled along the trough, although this was not associated with any major change in nutrient profile. Higher calcium levels per se in the trough, rather than the tank, relates to feed samples in the trough including all feed in front of the bird that included fine particles beneath the feeder chain. Particle separation was also seen with the mash feeds, although this was only during the first 18 m run of the feed trough.

Table 4.22 Particle segregation and calcium analysis of feed collected from farms using either mash or crumbles (%)

Type of feed	*Particle size (mm)*	*At feed tank*	*Distance along feed trough (m)*			
			+18	*+36*	*+72*	*+108*
Crumbles	*>2.36*	*46.0*	*29.8*	*25.3*	*20.6*	*16.0*
	>1.18	*28.8*	*26.5*	*25.5*	*24.7*	*23.7*
	>0.85	*6.9*	*9.4*	*10.1*	*10.9*	*11.1*
	>0.71	*3.4*	*5.5*	*6.1*	*6.7*	*7.1*
	>0.60	*3.2*	*5.6*	*6.2*	*6.7*	*7.1*
	<0.60	*11.7*	*23.2*	*26.8*	*30.3*	*33.8*
	%Calcium	*3.5*	*4.3*	*4.5*	*4.7*	*4.5*
Mash	*>2.36*	*17.3*	*10.0*	*8.3*	*8.5*	*10.5*
	>1.18	*22.7*	*21.1*	*20.0*	*19.6*	*21.0*
	>0.85	*11.9*	*13.4*	*13.2*	*14.5*	*15.1*
	>0.71	*7.2*	*8.9*	*9.0*	*9.2*	*9.0*
	>0.60	*7.4*	*8.6*	*9.0*	*9.3*	*8.2*
	<0.60	*33.5*	*38.0*	*40.5*	*38.9*	*36.2*
	%Calcium	*4.0*	*4.9*	*5.3*	*5.6*	*5.0*

4.6 Nutrition and shell quality

Nutrition can have a major impact on eggshell quality, and is often the first parameter considered when problems arise. After peak egg production, the layer produces a fairly consistent quantity of shell material for each egg, regardless of its size. As the egg gets larger, therefore, the shell necessarily gets thinner, and this becomes more prone to breakage.

Even with ideal conditions,4–5% of eggs leaving the farm will be graded as 'cracks', and together with cracked and broken eggs on-farm, means that 7–8% of eggshells break for various reasons. The composition of the shell is very consistent since the major constituent is calcium carbonate. When considering eggshell quality, the nutritional factors most often investigated are diet levels of calcium, phosphorus, and vitamin D_3. Since larger eggs have thinner shells, then levels of protein, methionine, and TSAA may also come under scrutiny.

A shell contains around 2 g of calcium the origin of which is the feed, with a portion of this cycling through the medullary bone. The most active period for shell formation usually coincides with the dark phase of the photoperiod, and so birds are not eating at this time (Figure 4.10). In the first 6 hours of the 24 h ovulatory cycle, there is virtually no shell deposition. This is the time of albumen and shell membrane secretion, and the time of redeposition of medullary bone. From 6 – 12 hr about 400 mg calcium are deposited, while the most active period is the 12 – 18 hr period when around 800 mg shell calcium accumulates. This is followed by a slower deposition of about 500 mg in the last 6 hr, for a total of around 1.7 g shell calcium, depending upon egg size.

During the evening, when shell calcification is greatest, a portion of the required calcium will come from the medullary bone reserves. The total medullary calcium reserves are probably less than 1 g. This reserve normally contributes no more than 0.1 g to a shell containing 2g calcium, yet are essential for the almost daily shell formation process of the modern layer. The medullary bone is composed of calcium phosphate, and so the quantity of calcium liberated for shell synthesis, is associated with a similar release of phosphorus.

Fig. 4.10 Shell mineral deposition over a 24h ovulation cycle

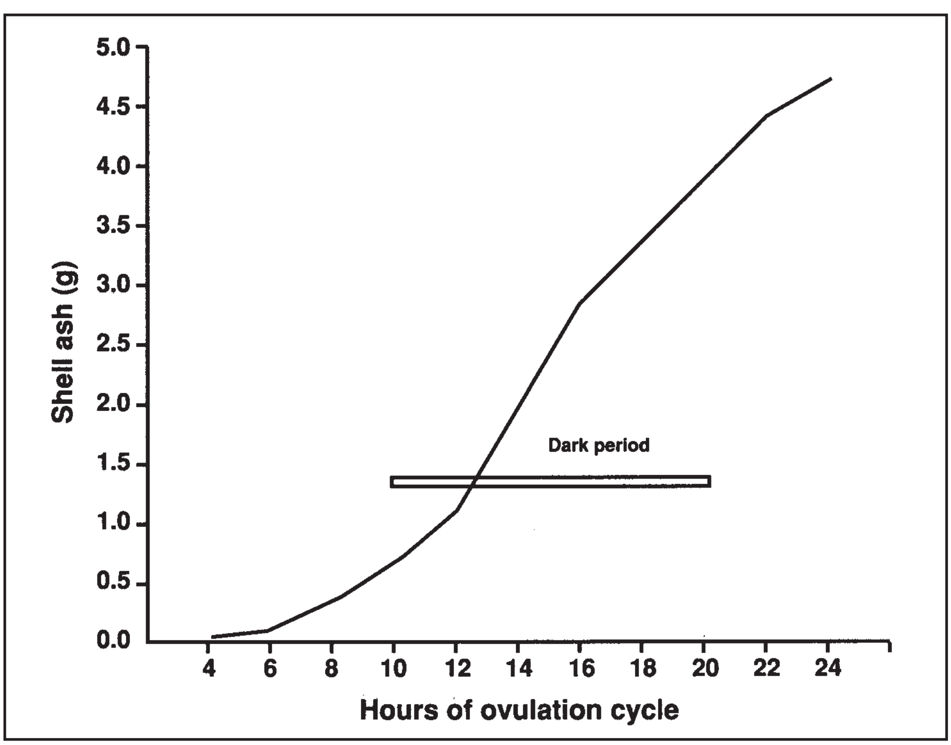
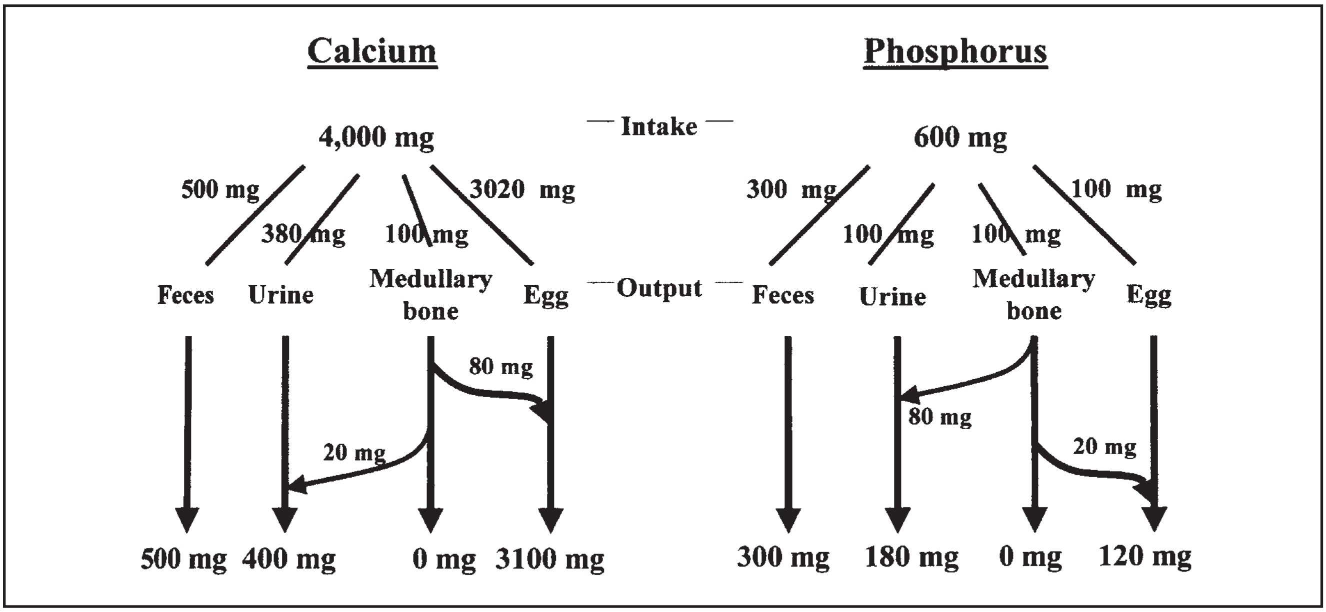


Fig. 4.11 Schematic of daily calcium balance in a laying hen.



Since there is little immediate need for this phosphorus, it is excreted and there is need for both calcium and phosphorus to replenish this medullary reserve during periods between successive ovulations. Figure 4.11 shows the calcium and phosphorus balance of a bird at around 35 weeks of age.

Figure 4.11 shows zero net accretion of calcium and phosphorus in medullary bone. It is likely that the quantity of medullary calcium and phosphorus reserves are maximum when the bird is around 30 weeks of age, and a slight negative balance over time contributes to reduced shell quality in older birds.

There is often discussion about the physical form and source of calcium supplied to layers. Calcium is usually supplied as limestone, or as oystershell which is much more expensive. Oystershell and large particle limestone are expected to be less soluble than is fine particle limestone, and so remain in the gizzard for longer and will hopefully be there in the period of darkness when the bird is not eating. Table 4.23 gives an example of descriptions used for limestone and associated relative solubility.

Table 4.23 Limestone types and solubility

Description	*Particle size (mm)*	*Relative[1] solubility*
Fine	*< 0.2*	*100*
Medium	*0.2 – 0.5*	*85*
Coarse	*0.6 – 1.2*	*70*
Extra coarse	*1.3 – 2.0*	*55*
Large (hen size)	*2.0 – 5.0*	*30*
Oystershell	*2.0 – 8.0*	*30*

[1] Reduced solubility results in longer retention within the digestive tract

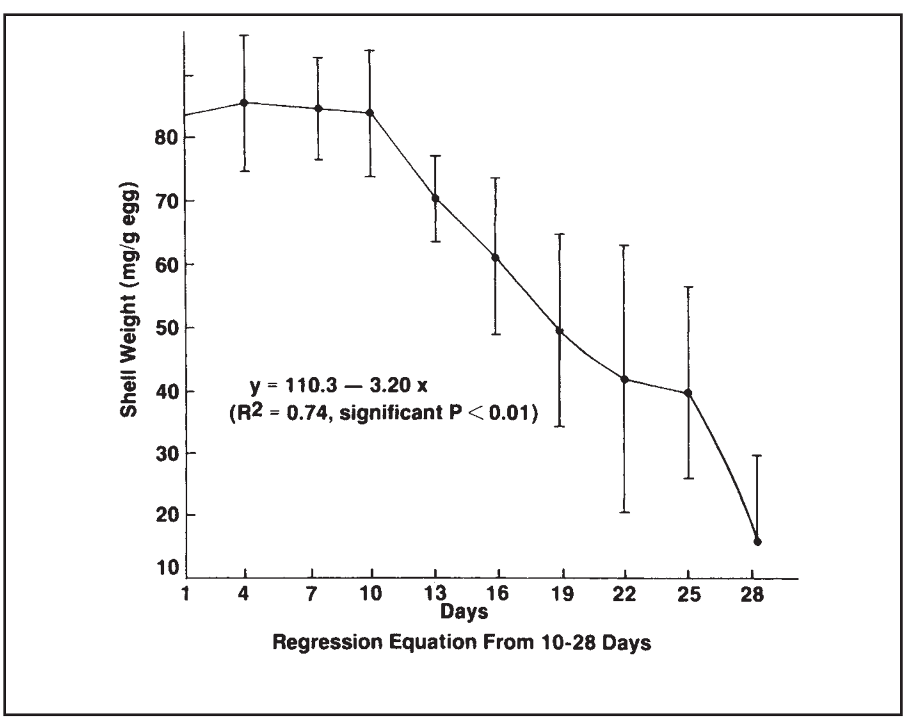
Twelve hours after feeding, there will likely be twice as much calcium in the gizzard from large vs. fine particle limestone. Oystershell is expected to have solubility characteristics similar to those of large particle limestone. The large particles are more important for older birds and seem to help maintain the quantity and activity of medullary bone. The only problem with large particle limestone is its abrasive characteristic with mechanical equipment.

Using particulate limestone or oystershell does allow the bird a degree of nutrient selection. The peak in calcium requirements coincides with shell calcification, and this starts each day in the late afternoon. If given a choice situation, layers will voluntarily consume more calcium at this time of day. In fact, a specific appetite for calcium is the likely reason for the late afternoon peak in feed intake seen when layers do not have the opportunity at nutrient/ingredient selection.

If birds do not receive adequate quantities of calcium there will be almost immediate loss in shell integrity. If the deficit is large, ovulation often ceases and so there is no excessive bone resorption. With marginal deficiencies of calcium, ovulation often continues, and so the birds rely more heavily on bone resorption. Total medullary bone calcium reserves are limited and so after production of 3 – 4 eggs on a marginally calcium deficient diet, cortical bone may be eroded with associated loss in locomotion. As calcium content of the diet decreases, there is a transient (1 – 2 d) increase in feed intake, followed by a decline associated with reduced protein and energy needs for egg synthesis. Calcium deficiency is exacerbated by high levels of dietary chloride (0.4 – 0.5%). In such dietary situations, there is greater benefit to feeding sodium bicarbonate. If birds are fed a calcium deficient diet, egg production and eggshell calcium return to normal in 6 to 8 days after the hens receive a diet adequate in calcium. After three weeks, the leg bones will be completely recalcified. The finding that the adrenal gland is enlarged in calcium deficiency indicates that this is a stress in the classical sense.

Calcium is the nutrient most often considered when shell quality problems occur,although

Fig. 4.12 Decline in shell weight for hens fed a diet devoid of Vitamin D_3 supplementation.



deficiencies of vitamin D_3 and phosphorus can also result in weaker shells. Vitamin D_3 is required for normal calcium absorption, and if inadequate levels are fed, induced calcium deficiency quickly occurs. Results from our laboratory suggest that diets devoid of synthetic vitamin D_3 are quickly diagnosed, because there is a dramatic loss in shell weight (Figure 4.12).

A more serious situation occurs when a marginal, rather than absolute deficiency of vitamin D_3 occurs. For example, birds fed a diet with 500 IU D_3/kg showed only an 8% decline in shell quality, yet this persisted for the entire laying cycle and would be difficult to detect in terms of cracked and reject eggs etc. A major problem with such a marginal deficiency of vitamin D_3 is that this nutrient is very difficult to assay in complete feeds. It is only at concentrations normally found in vitamin premixes, that meaningful assays can be carried out, and so if vitamin D_3 problems are suspected, access to the vitamin premix is usually essential. In addition to uncomplicated deficiencies of vitamin D_3, problems can arise due to the effect of certain mycotoxins. Compounds such as zearalenone, that are produced by Fusarium molds, have been shown to effectively tie up vitamin D_3, resulting in poor egg shell quality. Under these circumstances dosing birds with 300 IU D_3 per day, for three consecutive days, with water soluble D_3 may be advantageous.

Vitamin D_3 is effectively 'activated' by processes occurring first in the liver and then in the kidney. This first activation in the liver yields $25(OH)D_3$ while the second product is the result of further hydroxylation to yield $1,25(OH)_2D_3$. This latter compound is a very potent activator of calcium metabolism, although is not likely to be available as a feed ingredient. The first hydroxylation product, $25(OH)D_3$, is however, now available to the feed industry, and seems to promote increased calcium retention in layers (Table 4.24).

Table 4.24 Effect of Hy-D®25(OH)D_3 on daily calcium rentention

Hy-D® (µg/kg)	*Calcium retained (mg)*
0	410
10	450
20	500
40	530
60	540

Adapted from Coelho (2001)

Minimizing phosphorus levels is also advantageous in maintaining shell quality, especially under heat stress conditions. Because phosphorus is a very expensive nutrient, high inclusion levels are not usually encountered, yet limiting these within the range of 0.3% to 0.4%, depending upon flock conditions, seems ideal in terms of shell quality. Periodically, unaccountable reductions in shell quality occur and it is possible that some of these may be related to nutrition. As an example, vanadium contamination of phosphates causes an unusual shell structure, and certain weed seeds such as those of the lathyrus species, cause major disruptions of the shell gland.

Up to 10% reduction in eggshell thickness has been reported for layers fed saline drinking water, and a doubling in incidence of total shell defects seen with water containing 250 mg salt/liter. If a laying hen consumes 100 g of feed and 200 ml of water per day, then water at 250 mg salt/liter provides only 50 mg salt compared to intake from the feed of around 400 mg salt. The salt intake from saline water therefore, seems minimal in relation to total intake, but nevertheless, shell quality problems are reported to occur under these conditions. It appears that saline

water results in limiting the supply of bicarbonate ions to the shell gland, and that this is mediated via reduced activity of carbonic anhydrase enzyme in the mucosa of the shell gland. However, it is still unclear why saline water has this effect, in the presence of overwhelmingly more salt as provided by the feed. There seems to be no effective method of correcting this loss of shell quality in established flocks, although for new flocks the adverse effect can be minimized by adding 1 g vitamin C/liter drinking water.

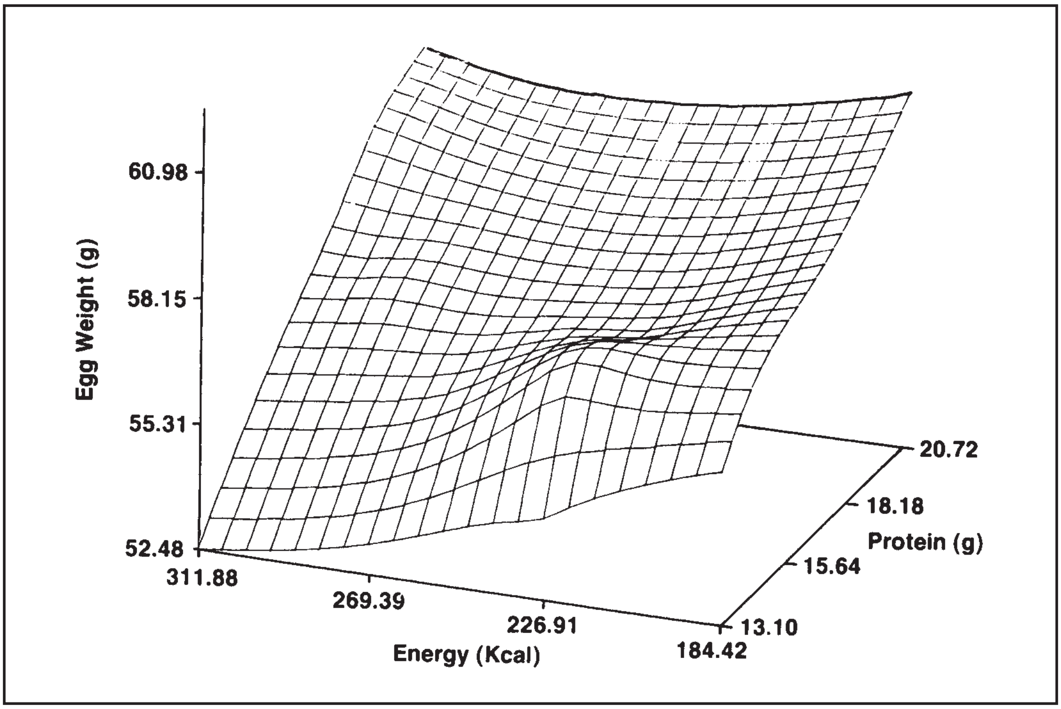
4.7 Controlling egg size

The main factor dictating the size of an egg is the size of yolk released from the ovary and this in turn is greatly influenced by body weight of the laying hen. The weight of the hen at maturity is therefore the major factor influencing egg size, and so it is expected that a large bird will produce more large grade eggs and vice-versa for a small bird. Assuming a given weight of bird, then nutrition can have some influence on egg size. Within a flock, birds that eat the most feed tend to produce the largest egg. For commercial flocks, where eggs are priced according to specific weight classes (grade) there is the need to maximize egg size as soon as possible. However, once 80% of eggs are falling into the largest, most economic weight category there is often need to temper further increases in egg weight, so as to sustain good eggshell quality. This early increase in egg size and late tempering of egg size can be influenced by nutrition to some extent. For the rapidly developing egg breakout market, weight of individual eggs assumes less importance than overall egg mass output. Apart from manipulating feed intake, egg size can sometimes be manipulated by adjusting dietary levels of energy and/or fat and/or linoleic acid, or by adjustment to levels of protein and/or methionine and/or TSSA. Assuming that diet nutrients are tied to energy level, and that the bird can maintain its energy intake, then energy *per se* has little effect on egg size. The effects of protein and energy on egg size are shown in Figure 4.13 which depicts the bird's response to a range of nutrient intakes. Unlike the situation with egg production (Figure 4.1) there is an obvious relationship between increased egg size and increased protein intake. At low protein intakes (less than 14 – 15 g/d) there is an indication of reduced egg size when energy intake is increased.

The response in egg weight to diet protein is most likely related to intakes of methionine or TSAA (Table 4.25). Roland *et al.* (1988) showed a consistent linear trend for increase in egg weight of young birds as the level of TSAA was increased from 0.65 to 0.81%. Analysis of this data indicates that egg size of young layers increases by 0.7 g for each 0.05% increase in diet TSAA. Table 4.26 shows a summary of 6 experiments reported by Waldroup *et al.* where a range of methionine levels were tested, at 0.2% cystine, for various ages of bird. As methionine level of the diet is increased, there is an almost linear increase in egg size.

As the bird progresses through a production cycle, the egg weight response to methionine changes slightly. In the first period, between 25 – 32 weeks, using 0.38 vs. 0.23% methionine results in a 5.6% increase in egg size (Table 4.26).

Fig. 4.13 Egg weight (18-66 weeks) in response to daily intakes of energy and protein.



Comparable calculations for the other age periods show 7.3% improvement from 38 – 44 weeks, and 6.7% and 6.0% at 51 – 58 and 64 – 71 weeks respectively. The egg weight response to methionine therefore, closely follows the normal daily egg mass output of the laying hen.

Dietary levels of methionine or TSAA's are most easily adjusted by use of synthetic methionine. There has recently been a resurgence in discussion regarding the efficacy of DL-methionine vs. methionine hydroxy analogue, and in particular Alimet®, as they influence layer performance and in particular egg weight. When unbiased studies are conducted, and the levels of methionine are comparable to industry standards, then DL-methionine is comparable to Alimet® on an equimolar basis. In terms of egg weight, Harms and Russell (1994) show similar responses to the two products (Table 4.27).

There has been a suggestion that L-methionine may, in fact, be superior to any other source. This product is not usually produced commercially, because routine manufacture of methionine produces a mixture of D- and L-methionine. This is the only amino acid where there is apparently 100% efficacy of the D-isomer. However, most research data indiates no difference in potency of L- vs DL-methionine sources.

Methionine acts as a methyl donor, and so the efficacy of methionine vs. choline is often discussed. While choline can spare some methionine in a diet, it is obvious that there are severe limitations to this process, and this becomes most obvious when egg size, rather than simply egg production, is a major consideration. Data from Parsons and Leeper (Table 4.28) clearly shows the advantage of using methionine over choline in terms of egg size, and that this effect becomes most critical as diet crude protein level is reduced.

Table 4.25 Effect of TSAA on egg weight from young laying hens (g)

Bird age (wks)	*Total sulphur amino acids (%)*				
	0.65	***0.69***	***0.72***	***0.76***	***0.81***
25	49.3	49.1	50.2	50.2	51.6
29	53.8	53.5	53.9	54.4	54.7
33	55.3	55.1	56.0	56.0	56.3

Adapted from Roland et al. (1998)

Table 4.26 Effect of methionine on egg weight – mean of 6 experiments

Bird age (wks)	*% Diet methionine with 0.2% cystine*					
	0.23	***0.26***	***0.29***	***0.32***	***0.35***	***0.38***
25 - 32	49.8	51.0	51.9	52.1	52.0	52.6
38 – 44	53.2	55.0	56.4	56.3	56.3	57.1
51 - 58	56.2	57.9	59.6	59.2	59.2	60.0
64 - 71	56.8	59.4	59.5	59.5	59.5	60.2

Adapted from Waldroup et al. (1995)

Table 4.27 Effect of methionine source on layer performance [1]

Diet methionine (%)	*Egg weight (g)*			
	Exp #1		*Exp #2*	
	DL	*Alimet®*	*DL*	*Alimet®*
0.228 (basal)	54.5	54.5	51.5	51.5
0.256	56.2	55.3	53.2	52.7
0.254	56.8	56.8	55.1	56.2
0.311	57.6	57.2	55.9	55.7
0.366 - 378	58.0	57.5	57.0	56.8

1Mean 80% egg production *Harms and Russell (1994)*

Table 4.28 Egg size with methionine vs. choline (23 – 35 wks)

Diet protein	*Supplement*	*Egg production (%)*	*Egg weight (g)*
	None	82.8	53.2
16%	0.1% methionine	84.0	56.6
	0.1% choline	82.4	54.0
	None	72.8	52.5
14%	0.1% methionine	84.5	54.9
	0.1% choline	78.9	51.9

Adapted from Parsons and Leeper (1984)

Table 4.29 Effect of linoleic acid on egg weight (g)

Bird age	*Linoleic acid (% of diet)*			
(wks)	***0.79***	***1.03***	***2.23***	***2.73***
20 – 24	*60.5*	*61.3*	*61.4*	*61.4*
25 – 28	*60.8*	*61.7*	*62.0*	*62.0*
29 – 32	*62.8*	*63.7*	*63.1*	*63.4*

Adapted from Grobas et al. (1999)

Table 4.30 Effect of reducing dietary protein level on egg size of 60wk-old layers (Av. for 2, 28-day periods)

Dietary protein level (%)	*Egg production (%)*	*Av. feed intake per day (g)*	*Egg wt. (g)*	*Daily egg mass (g)*	*Av. protein intake per day (g)*
17	*78.8*	*114*	*64.8*	*51.0*	*19.4*
15	*77.5*	*109*	*64.3*	*49.7*	*16.4*
13	*78.3*	*107*	*62.2*	*49.1*	*13.9*
11	*72.7*	*108*	*61.7*	*45.1*	*11.9*
9	*54.3*	*99*	*58.2*	*36.1*	*8.9*

All diets 2800 kcal ME/kg

The other nutrient most often considered when attempting to maximize early egg size is linoleic acid. In most situations, 1% dietary linoleic acid meets the bird's needs, although for maximizing egg size, levels as high as 2% are often used. It is difficult to separate the effect of linoleic acid versus that of energy, since supplemental fat is usually used in such studies. Assuming that the bird is consuming adequate amounts of energy, then the response to extra dietary linoleic acid is minimal (Table 4.29). In this study there was no increase in egg size with levels of linoleic acid greater than 1%, which is the quantity normally found in a corn based diet.

As layers get older, then depending on strain of bird, it is often economical to try and temper subsequent increases in egg size, in order to help maintain shell quality. It seems more difficult to temper egg size than to increase egg size. For older birds, body weight is still the major factor influencing egg size, and so it is difficult to control egg size if birds are overweight. Reducing the level of linoleic acid has no effect on egg size, and so the only options are for reducing crude protein and/or methionine levels in the diet. Our studies indicate that protein levels around 13% and less are necessary to bring about a meaningful reduction in egg size (Table 4.30). However, with protein levels much less than this, loss in egg numbers often occurs.

Methionine levels can also be adjusted in an attempt to control late cycle egg size. Results of Peterson show some control of egg size with reduced methionine levels (Table 4.31). However, these results are often difficult to achieve under commercial conditions because reduction in diet methionine levels often leads to loss in egg numbers and body weight. Phase feeding of amino acids must therefore be monitored

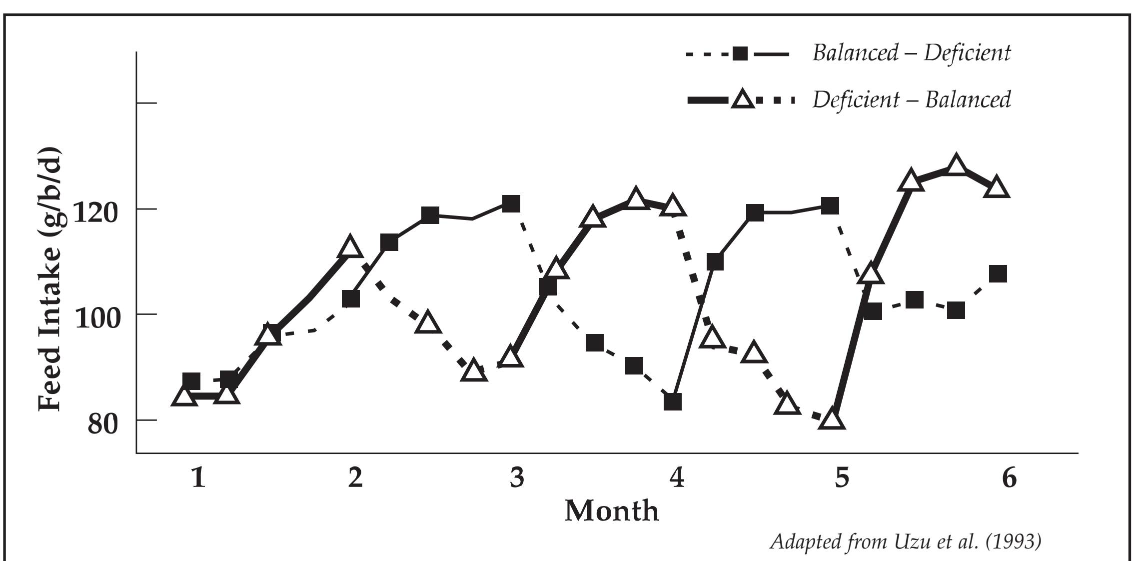
very closely, since the bird is very sensitive to 'deficiencies' of methionine. Uzu *et al.*, (1993) using brown egg birds show the sensitivity of changes in feed intake (Figure 4.14) when birds were alternated monthly between adequate (0.33% methionine; 0.6% TSAA) and deficient diets (0.23% methionine; 0.5% TSAA). Layers were very sensitive to levels of methionine and increased their feed intake apparently in an attempt to maintain methionine intake. Interestingly this same precise pattern of feed intake was seen when diets were changed weekly. These data confirm that it is important not to reduce methionine levels too much or too quickly, since any economic saving can be offset by increase in feed intake. Waldroup *et al.* (1995) suggest that for older birds the methionine and TSAA requirements of layers are greater for egg numbers than for optimizing egg weight (Table 4.32). These data reinforce the concept that phase feeding of methionine to control egg size may have a detrimental effect on egg numbers. During peak egg mass output (38 – 45 weeks) the methionine requirement for egg size is greater than for egg numbers, while the latter requirement peaks at 51- 58 weeks of age.

Table 4.31 Methionine and late cycle egg size (g)

Daily methionine intake (mg/d)	*Exp. 1 (38-62 wk)*	*Exp. 2 (38 – 70 wk)*	*Exp. 3 (78 – 102 wk)*
300	60.1[a]	63.7[a]	66.3[a]
285	60.3[a]	63.1[b]	65.5[b]
270	59.1[ab]	62.0[c]	64.0[c]
255	58.5[b]	62.0[c]	63.9[c]
Average egg prod (%)	86	80	75

Adapted from Peterson et al. (1983)

Fig. 4.14 Feed intake of brown- egg layers hens fed adequate on deficient levels of methionine. (g/b/d)



This data suggests that we should be very careful in reducing methionine levels much before 60 weeks of age.

As stated at the outset of this section, mature body weight is the main determinant of egg size, and this applies particularly to late-cycle performance. The best way to control late cycle egg size is through manipulation of body weight at time of initial light stimulation. Larger birds at maturity will produce much larger late cycle eggs and vice versa. There is an obvious balance necessary between trying to reduce late cycle egg size without unduly reducing egg size in young birds.

Table 4.32 Estimated methionine and methionine + cystine requirements (mg/day) for egg number, weight and mass.

	Bird age (wks)	Egg #	Egg weight	Egg mass
Methionine	25 – 32	364[b]	356[b]	369[b]
	38 – 45	362[b]	380[a]	373[b]
	51- 58	384[a]	364[a]	402[a]
	64 - 71	374[ab]	357[b]	378[b]
Methionine + Cystine	25 – 32	608[b]	610[ab]	617[b]
	38 – 45	619[b]	636[a]	627[b]
	51 – 58	680[a]	621[ab]	691[a]
	64 - 71	690[a]	601[b]	676[a]

Adapted from Waldroup et al. (1995)

4.8 Diet and egg composition

Tables 4.33 – 4.35 show egg composition and nutrient content together with an indication of the contribution of these nutrients to human nutrition.

Table 4.33 Egg components and major nutrients (60 g egg)

		Yolk	Albumen	Shell
Wet weight	(g)	19.0	35.0	6.0
Dry weight	(g)	10.0	4.2	5.9
Protein[1]	(%)	17.0	11.0	3.0
	(g)	3.2	3.9	0.2
Fat	(%)	32.0	-	-
	(g)	6.0	-	-
Carbohydrate	(%)	1.0	1.0	-
	(g)	0.2	0.4	-
Minerals	(%)	1.0	0.6	95.0
	(g)	0.2	0.2	5.7

[1] *As is basis*

Table 4.34 Vitamin and mineral composition of contents from a 60 g egg

Vitamins		
A	*(I.U.)*	*300*
D_3	*(I.U.)*	*30*
E	*(I.U.)*	*2*
K	*(mg)*	*.02*
B_1	*(mg)*	*.06*
B_2	*(mg)*	*.18*
B_6	*(mg)*	*.20*
B_{12}	*(mg)*	*.001*
Pantothenic acid	*(mg)*	*1.2*
Folacin	*(mg)*	*.008*
Niacin	*(mg)*	*.06*
Choline	*(mg)*	*350*
Biotin	*(mg)*	*.01*
Minerals (mg)		
Calcium		*30*
Phosphorus		*130*
Sodium		*75*
Chloride		*100*
Potassium		*80*
Magnesium		*7*
Manganese		*2*
Iron		*1*
Copper		*2*
Zinc		*1*
Iodine		*.02*
Selenium		*.01*

Table 4.35 Contribution of eggs to Human DRI for selected nutrients

Nutrient	*Two eggs supply the following of an adult's daily requirement (%)*
Protein	*20*
Energy	*8*
Calcium	*10*
Phosphorus	*20*
Iron	*20*
Vitamin A	*25*
Vitamin D_3	*20*
Thiamin	*10*
Riboflavin	*30*
Niacin	*15*

i) Yolk color - In most markets it is important to control and maintain the color of the yolk. The yellow/orange color of the yolk is controlled by the bird's intake of xanthophyll pigments and in particular lutein, zeaxanthin and various synthetic pigments such as canthaxanthin and apocarotenoic esters. As the level of dietary xanthophylls increases, there is increase in yolk color as assessed on the Roche Scale of 1 to 15. Figure 4.15 shows the general relationship between xanthophyll content of the feed and egg yolk on the Roche Color Score.

The desired yolk color will vary in different markets, although a color score of 8 – 9 is common in many areas. A high degree of pigmentation is a score of 11 – 12 while for some specialty pasta markets, there may be need to achieve 14 – 15. The common feed ingredients high in xanthophylls, are corn and corn gluten meal as well as dehydrated alfalfa. Table 4.36 shows the expected color score contributed by the various levels of each of these ingredients.

Fig. 4.15 Roche color scale and dietary xanthophylls

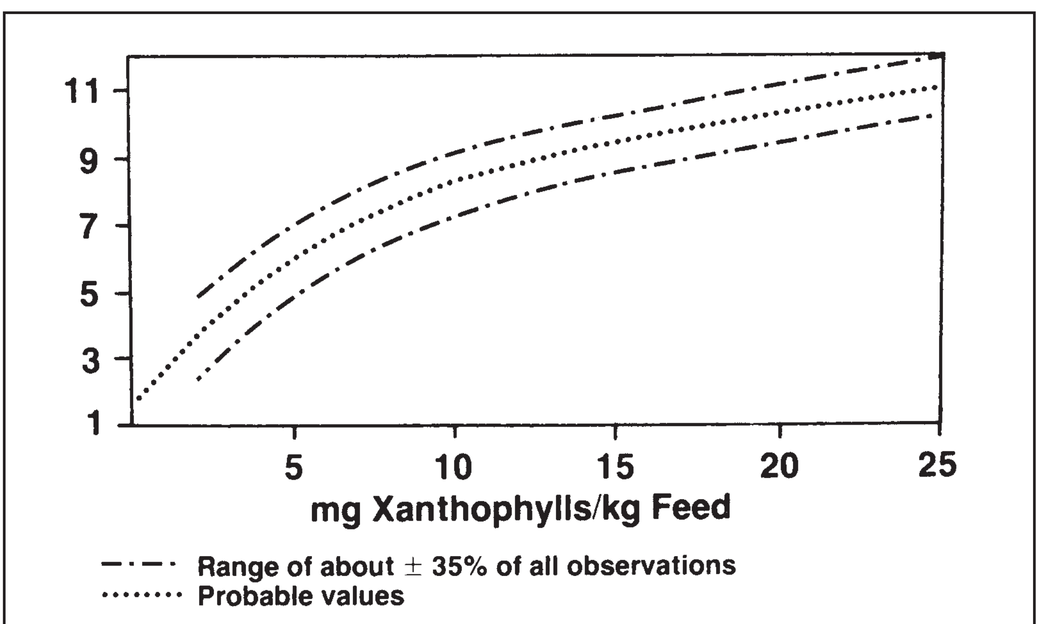


Table 4.36 Ingredients and yolk color

Ingredient	*Inclusion level (%)*	*Yolk color (Roche scale)*
	0	*2*
	20	*6*
Corn	*40*	*8*
	60	*9*
Corn	*2*	*6*
gluten	*6*	*9*
meal	*8*	*14*
	2	*4*
Alfalfa	*6*	*7*
meal	*8*	*9*

Carotenes themselves have little pigmenting value for poultry, although the various hydroxylated carotenes are excellent pigments and the bird preferentially stores these in yolk, body fat, and its shanks. The red/orange colors can be produced by adding synthetics such as canthaxanthin, although usually this degree of coloring is unacceptable to most consumers. These pigments can be used in limited quantities as long as the diet has a base level of xanthophylls – otherwise the yolk color tends towards an objectionable red, rather than acceptable orange color. These red pigments also produce undesirable color in noodles made from egg yolk, and so care must be taken in selection of pigmenting agents in eggs destined for industrial uses. In most markets, it is common to add 7 – 8 g of supplemental xanthophylls per tonne of feed. Levels below 5 g/tonne usually result in too pale a yolk.

There are a number of dietary and management factors which can reduce the effective deposition of xanthophylls in the yolk. Ingredients which are potential oxidizing agents, such as minerals and certain fatty acids, have been shown to reduce pigmentation. High levels of vitamin A, as sometimes used during water medication for various stress situations, have been shown to cause temporary loss in yolk pigmentation. High environmental temperature, coccidiosis and aflatoxin contamination of feed are also implicated in production of pale colored yolks. Natural pigments in cereals tend to decline with prolonged storage, with up to 50% loss reported at elevated temperatures. Without blending of corn therefore, a slight natural loss in pigments is expected to cause subtle loss in yolk color throughout the year. Yolk color seems to be enhanced when high levels of vitamin E are used, and when the diet contains antioxidants.

In addition to pigmenting the yolk for marketing needs, there is growing evidence that lutein and zeaxanthin may be important nutrients for humans. These pigments concentrate in the macular region of the eye, and are thought to help prevent macular degeneration, which together with cataracts, are the leading causes of blindness in developed countries. The macula is found on the back wall of the eye and is responsible for sharp central vision. The irreversible and untreatable degeneration of the macula leads to loss of central vision and eventually total blindness. Some 20% of North Americans over the age of 65 have some degree of macular degeneration. It seems that diets rich in lutein and zeaxanthin increase the level of these pigments in the macula and acting as antioxidants and/or filters to damaging blue light, protect this sensitive area of the inner eye surface. Current intakes of lutein and xeaxanthin in most countries are less than 1 mg/d which is much less than the 5 – 6 mg/d now suggested for prevention of macular degeneration and also occurrence of cataracts. It seems possible to further increase the xanthophyll content of the layers diet, to produce eggs enriched in this important nutrient.

ii. Egg yolk fatty acids – The fatty acid content of the yolk is greatly influenced by the fatty acid profile of the bird's diet. Since there is now concern about our consumption of saturated fatty acids, it seems beneficial to manipulate the ratio of unsaturates:saturates in the yolk. This is achieved by including proportionally more unsaturated fatty acids in the bird's diet. Additionally there is the opportunity for feeding the bird specific polyunsaturates that are now recommended for improved human health. These fatty acids are termed omega-3 fatty acids, as opposed to omega-6 fatty acids which are the most common unsaturates in ingredients such as corn oil and soybean oil. The omega-3 fatty acids of greatest interest are linolenic acid, (18:3n3) eicosapentaenoic acid (20:5n3) and docosahexaenoic acid (22:6n3), and these are known to reduce the risk of chronic heart disease.

Individuals suffering from CHD seem to have lower levels of linolenic acid in their adipose tissue. Linolenic acid is a precursor of prostaglandin E, which is reported to be a coronary vasodilator, an inhibitor of free fatty acid release (as occurs during acute CHD) and is one of the most potent inhibitors of platelet aggregation. Unfortunately, the diet of most humans is not well fortified with linolenic acid, which is most commonly found in plant tissues. However, the chicken has the somewhat unique ability to divert large quantities of linolenic acid into the egg when its diet contains high levels of this nutrient. This situation is most easily achieved by including 8 – 10% flaxseed in the bird's diet. There seems to be a linear relationship between flax inclusion level and egg linolenic acid content. Figure 4.16 was compiled from 6 different research studies involving linolenic acid enrichment of eggs.

Fig. 4.16 Relationship between dietary flaxseed and egg omega-3 content.

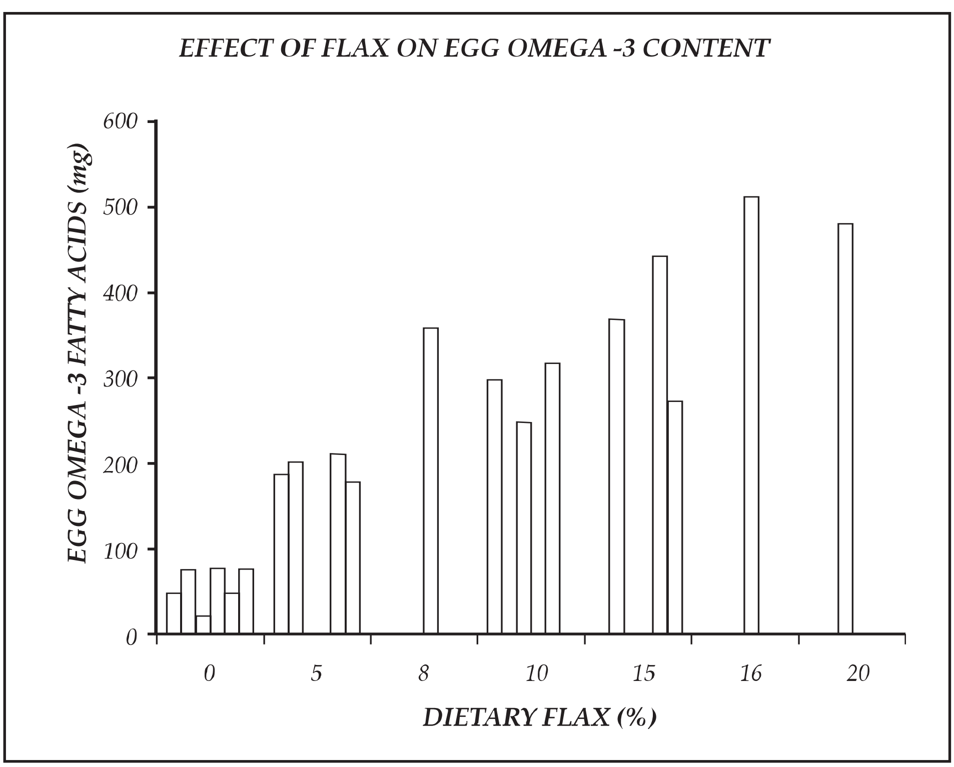


Table 4.37 Effect of 2% dietary menhaden oil on egg organoleptics

(Subjective score 0-10)

Category	*Control*	*Menhaden oil*	
		2%	**2%Deodorized**
Aftertaste	6.3[a]	7.5[ab]	8.2[b]
Off-Flavor	3.9[a]	6.5[b]	6.9[b]

Adapted from Gonzalez and Leeson (2000)

In most markets such designer eggs need to have a guarantee of 300 mg omega-3 fatty acids, and so this necessitates around 10% flax in the birds diet (Figure 4.16). Perhaps the most important fatty acid for prevention of CHD in humans is docosahexaenoic acid (DHA). Flax does not contain very much DHA and egg DHA level seems to quickly plateau at 70 – 80 mg with 5% flaxseed (Figure 4.17).

A more useful and concentrated source of DHA is fish oils. With menhaden oil, it is possible to increase egg DHA up to 200 mg with inclusion of 2% in the bird's diet (Figure 4.18). Unlike the situation with using flaxseed, the inclusion of fish oil in the bird's diet will result in a change in taste of the egg. In a recent study, we fed layers 2% menhaden oil or 2% deodorized menhaden oil to study the effect on DHA enrichment. When these eggs were assessed in taste panels, there was a distinct negative effect regarding 'after taste' and off-flavors. Deodorizing the oil prior to use in the layer diet had no beneficial effect on egg taste (Table 4.37).

Fig. 4.17 Effect of dietary flaxseed on egg DHA

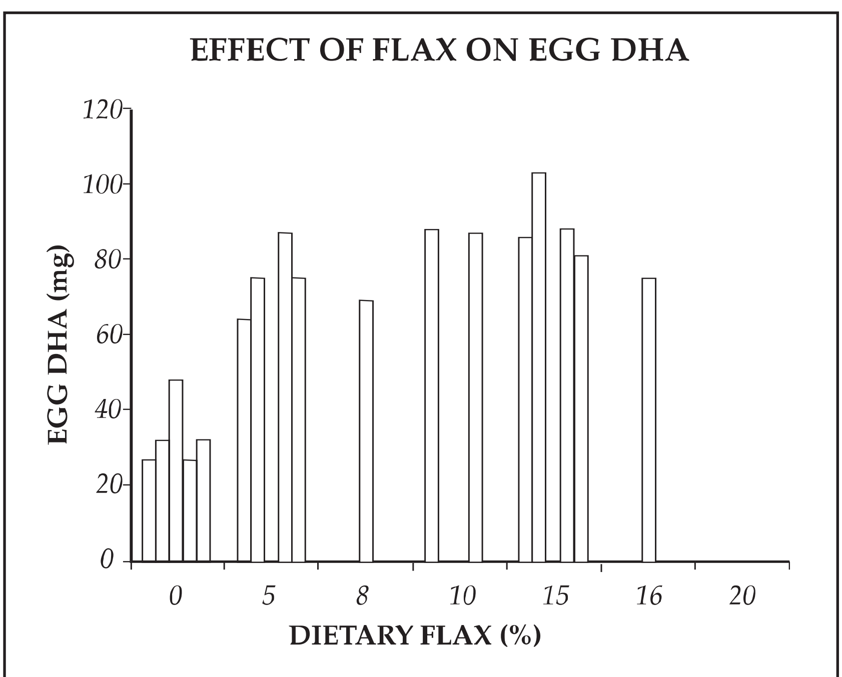


Fig. 4.18 Effect of dietary menhaden on egg DHA content.

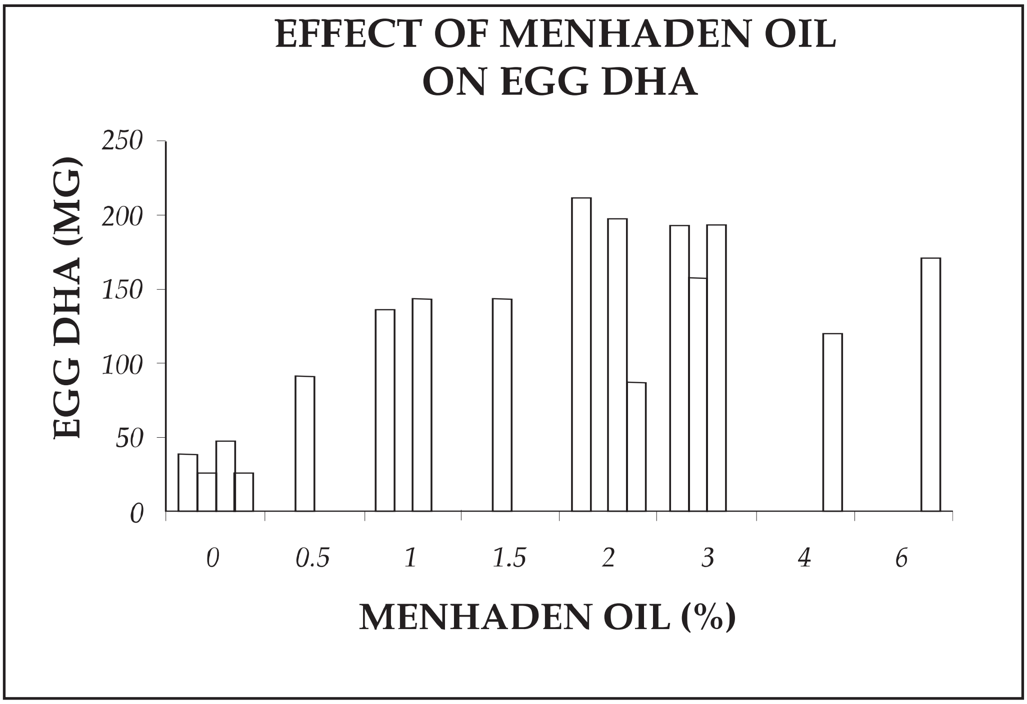
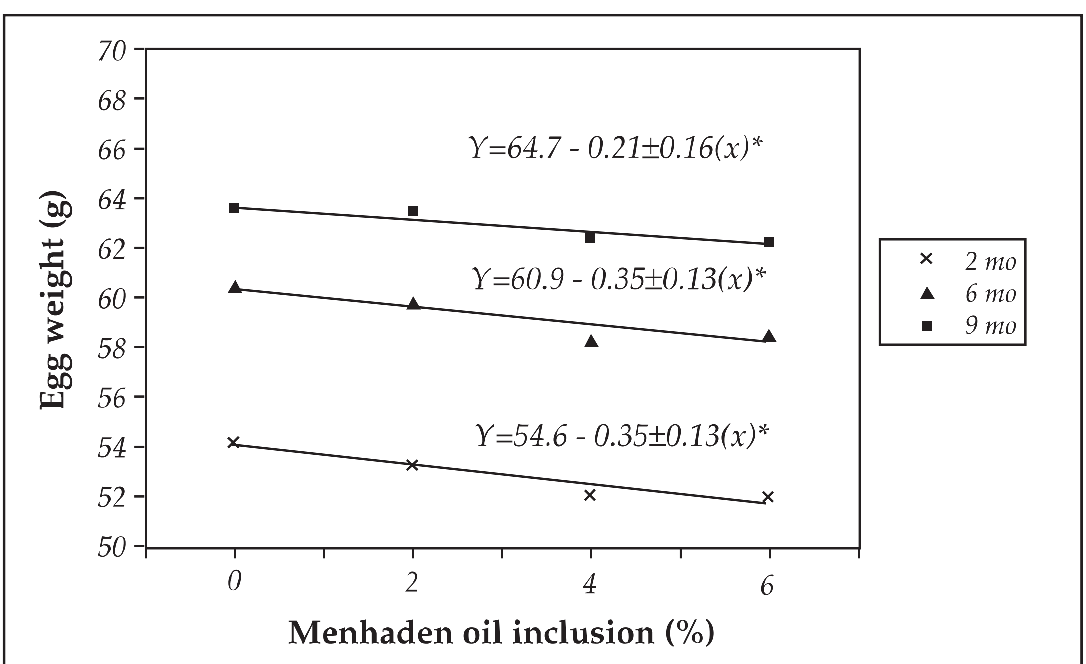


Fig. 4.19 Effect of dietary menhaden oil on egg weight of layers at 2,6 and 9 months of production.



(Gonzalez and Leeson, 2000)

Regardless of bird age, the inclusion of menhaden oil also reduced egg size by up to 0.35 g per 1% fish oil inclusion in the diet (Figure 4.19). The reduction in egg weight may be related to the decrease in circulating triglycerides, which is common in birds fed fish oils, so limiting lipids for yolk synthesis.

Table 4.38 summaries the enrichment of eggs with omega-3 fatty acids and DHA in response to using flaxseed and fish oil.

Table 4.38 Egg enrichment of fatty acids

Fatty acid	*Ingredient*	*Enrichment*
Total omega-3	*1% Flaxseed*	*40 mg*
DHA	*1% Fish oil*	*50 mg*
DHA	*1% Flaxseed*	*8 mg*
CLA	*1% CLA*	*50 mg*

For total omega-3's in response to flax and DHA with fish oil, there is a linear response within the range of ingredient levels likely to be used in a diet. There is a distinct plateau with DHA in response to flaxseed, where regardless of flaxseed levels, egg enrichment does not get much beyond 70 mg /egg.

Conjugated linoleic acid (CLA) is a positional isomer of linoleic acid that is claimed to have potent anticarcinogenic properties. There are a few natural ingredients rich in CLA, and so studies to date have used CLA itself as a feed ingredient. Each 1% inclusion of dietary CLA seems to result in 50 mg deposition of CLA in the egg.

iii) Egg cholesterol – Eggs naturally contain a high level of cholesterol because of its role in sustaining the developing embryo. Cholesterol has many and varied functions in the embryo including its role as a structural component of cell membranes, and as a precursor for sex and adrenal hormones, vitamin D, and the bile acids. Young chicks do not have the enzymes necessary for cholesterol synthesis, which emphasizes the importance of cholesterol being deposited in the egg. An egg contains about 180 mg cholesterol and it seems very difficult to reduce this without adversely affecting other production parameters.

Factors that influence egg cholesterol content include the hen's body weight and her intake of energy and fat. Diet fat *per se* does not seem to be a factor, although in most instances high fat diets imply that high-energy diets are used. Restricting the energy intake of laying hens results in less cholesterol being deposited in the egg, although this is usually associated with a reduction in egg production. The influence of dietary energy and body weight of the hen on egg cholesterol is mediated through their effects on yolk size and egg size. Reducing energy intake in order to achieve a measurable reduction in egg cholesterol concentration has the disadvantage of adversely affecting both egg production and egg weight.

Dietary fiber influences cholesterol metabolism by a possible combination of different processes. These include lowered cholesterol absorption and resorption, binding with bile salts in the intestinal tract, shortening the intestinal transit time, and increasing fecal sterol excretion. Alfalfa is one of the most effective sources of fiber with minimal detrimental effects on egg size, egg production, and feed efficiency. Alfalfa seems to efficiently bind bile acids.

Reduction in egg cholesterol achieved by such dietary manipulations is, however only marginal, with little evidence to suggest a commercially important change.

There is an indication that very high levels of dietary copper can reduce egg cholesterol content. High levels of copper decrease the production of liver glutathione, which in turn regulates cholesterol synthesis through stimulation of methyl glutaryl Co-A. Using up to 250 ppm dietary copper has been reported to reduce egg cholesterol by up to 25% (Table 4.39). In this particular study, egg production was unaffected, although in more long-term trials, reduced egg output has been recorded. Of concern today is the bioaccumulation of copper in the manure, since the vast majority of the dietary copper is not retained (Table 4.39).

One reason for the insensitivity of egg cholesterol to diet manipulation is the basic biochemistry of the lipoproteins within eggs. Egg cholesterol is determined by the cholesterol content of individual yolk lipoprotein moieties, rather than by the bird's plasma cholesterol concentration. Given that most cholesterol in lipoproteins is associated with the surface layers, reduction in egg cholesterol content can therefore occur only when the lipoprotein particle size is increased. Such a scenario will reduce the contribution of surface cholesterol molecules relative to total fat. Unfortunately, an increase in lipoprotein particle size will tend to reduce the efficiency of the critical transport of bigger sized 'molecules' through the follicle wall.

iv) Egg vitamins - Many food items are now enriched with vitamins and consumers consider these as healthy products. The egg contains both fat and water soluble vitamins and there is potential for enrichment. Currently, most omega-3 enriched eggs also contain additional vitamin E, ostensibly as a natural antioxidant. It is likely that the fat soluble vitamins will be the easiest group to manipulate. The influence of dietary vitamin intake on vitamin enrichment of the egg is quite variable among vitamins. Riboflavin level in the yolk and albumen responds rapidly to manipulating the dietary level of this vitamin. Similarly, the egg content of vitamin B_{12} is almost exactly proportional to diet content over one to four times normal inclusion levels. There does not seem to be a ceiling on vitamin B_{12} transfer to the eggs although a plateau is quickly reached with riboflavin enrichment. There are some natural changes in egg vitamin levels related to age of bird. Riboflavin, pyridoxine and vitamin B_{12} levels of eggs decline while biotin level increases with increasing age of hens. The decline in egg content of some vitamins with increasing age is related to a higher rate of production, since egg output is not completely compensated for by increasing dietary intake of these vitamins. Thiamin content of eggs from White Leghorn hens was reported to be about 50% greater than that of eggs laid by Rhode Island Reds or Barred Plymouth Rocks fed the same diet.

Table 4.39 Effect of dietary copper on egg cholesterol and copper accumulation in yolk and manure

Diet Cu ppm	*Egg cholesterol (mg) 4 wk*	*8 wk*	*Yolk copper (µg)*	*Manure copper (ppm DM)*
6	*163a*	*176a*	*9.4*	*36*
130	*121b*	*123b*	*11.9*	*540*
255	*114b*	*116b*	*13.9*	*937*

Adapted from Pesti and Bakalli (1998)

Naber (1993) in a review of factors influencing egg vitamin content concluded that feed vitamin content has the greatest and most widespread influence on egg vitamin content. Using data from studies that reported diet vitamin level and feed intake on the one hand, and egg output, i.e. egg weight and production on the other, Naber calculated the efficiency of vitamin transfer into eggs as a function of intake (Table 4.40). The transfer efficiency of vitamin A was very high (up to 80%), but this dropped markedly when the dietary level was raised to four times requirement. This is an indication of the possibility of egg enrichment with vitamin A, even though this trend declines at high levels of diet vitamin enrichment. The transfer of dietary vitamin B_{12} into eggs was as efficient as for riboflavin, pantothenic acid and biotin, e.g. about 50% with dietary levels at one to two times requirement. Unlike riboflavin, however, this level of transfer efficiency continued in the case of vitamin B_{12} even at very high dietary levels of up to 40 times requirement. Clearly, substantial enrichment of eggs with vitamin B_{12} is possible.

All of the research work conducted to date has studied the potential of enriching single vitamins in isolation. In a recent study, we attempted to enrich all vitamins. Considering the expected transfer efficiency (Table 4.40) a vitamin premix was formulated that contained 2 – 10 times the regular level of inclusion. After feeding layers for 60 d, eggs were assayed for all vitamins (Table 4.41).

The results were somewhat discouraging in that only for vitamin B_{12} and vitamin K were we able to achieve adequate enrichment to supply 100% of DRI. The enrichment for other vitamins was quite variable, where, for example, with pantothenate there was little response, while for vitamins D_3 and E there was some 3-fold increase in egg concentration. It is possible that at the higher levels of vitamins used, there is some antagonism and/or preferential loading of absorption mechanisms.

Table 4.40 Classification of vitamins by relative transfer efficiency from diet to egg

Transfer efficiency		*Vitamin*
Very High	*(60 – 80%)*	*Vitamin A*
High	*(40 – 50%)*	*Riboflavin*
		Pantothenic acid
		Biotin
		Vitamin B_{12}
Medium	*(15 – 25%)*	*Vitamin D_3*
		Vitamin E
Low	*(5 – 10%)*	*Vitamin K*
		Thiamin
		Folacin

Adapted from Naber (1993)

v. Yolk mottling **-** Egg yolk mottling continues to be a problem that appears sporadically in a number of flocks. Although the condition has been known for some time, there appears to be no definite evidence as to its cause or of ways to alleviate it. Diet has been implicated, but there is no real evidence that nutrition is a factor with the majority of mottling problems that appear. However, it is known that certain feed additives such as nicarbazin can cause a mottling condition if they are inadvertently added to a laying diet. Most cases of yolk mottling are reported in the spring of the year and most often 'disappear' during the summer or fall. However,

Table 4.41 Vitamin content of eggs from hens fed regular or enriched levels of vitamins

Vitamin	Units	Regular egg	Enriched egg	DRI[1]	% DRI
Biotin	μg/kg	16	18	30	60
Folic acid	μg/kg	8.7	10	400	3
Niacin	mg/kg	0.04	0.08	16	1
Pantothenate	mg/kg	0.76	0.77	5	15
Vit A	IU/kg	17.7	22.5	270	8
Vit B_1	mg/kg	0.048	0.06	1.2	5
Vit B_2	mg/kg	0.21	0.25	1.3	19
Vit B_6	mg/kg	0.027	0.03	1.3	2
Vit B_{12}	μg/kg	0.872	3.37	2.4	140
Vit D_3	μg/kg	0.39	1.1	5	22
Vit E	mg/kg	1.3	3.78	15	25
Vit K	mg/kg	0.12	0.13	0.12	108

[1] Daily recommended intake for adult

Table 4.42 Yolk mottling as influenced by temperature

	Haugh units	Yolk color index	Severity of mottling (%)
Fresh eggs	85.4	11.3	7.1
Eggs held 1 week at 12.5˚C	70.8	10.9	45.6
Eggs held 2 weeks at 12.5˚C	66.7	10.9	44.0
Eggs held 1 week at room temperature	-	-	47.6
Eggs held 2 days at 31.7˚C	-	-	60.0

whether the season of the year or the type of laying house management is a factor has not been proven. Table 4.42 shows the result of a study in which eggs held for various lengths of time and under different environmental conditions, were checked for severity of yolk mottling. It is evident that the majority of mottling appears during storage. Storing, even at ideal temperature for one week, can result in a marked increase in the condition. It has been suggested that the modern strains of birds are more prone to yolk mottling than are traditional strains although research data does not confirm this assertion.

The vitelline membrane surrounding the yolk is much weaker when yolks are mottled. With severe mottling it is very difficult to manually separate the yolk without breaking the membrane. It is not known if the change in vitelline membrane integrity is a cause or effect of mottled yolks. In terms of nutrition, nicarbazin or high gossypol cottonseed are most usually implicated.

vi Albumen quality – The main factor influencing albumen quality is storage time. Over time, especially at temperatures > 10˚C, there will be a breakdown of thick albumen, and so loss in egg quality.

Over the last few years there has been increasing concern about the quality of the thin rather than thick albumen in fresh eggs. Most measures of albumen quality, such as Haugh unit, only measure characteristics of the thick albumen, and so apparently 'Grade A' eggs can have problems with the thin albumen. In certain birds, we see the area of thin albumen to be as much as 120 sq. cm., compared to 60 – 70 sq. cm. for a 'normal' egg. These spreading albumens are especially problematic in the fast-food industry where eggs are prepared on flat-surface grills. We have tested various levels of protein and amino acids, and fed birds diets of vastly different acid-base balance, and seen no effect on this phenomenon. We have selected birds producing normal vs. spreading albumen and their offspring show similar characteristics. The current thin albumen problem therefore seems to be an inherited characteristic.

Magnesium plays a role in stabilization of thick albumen, and so there have been studies aimed at improving albumen quality by feeding layers high levels of this mineral. In one study, feeding 4 – 8,000 ppm Mg on top of a basal level of 1500 ppm did help maintain thick albumen after egg storage for 20 d at 20˚C. In control eggs, there was almost 70% liquification of thick albumen, while in magnesium enriched birds there was only 25% conversion of thick to thin albumen. Unfortunately, high levels of dietary magnesium cause loss in shell quality and so this has to be considered if magnesium salts are used in layer diets.

There have been inconsistent reports of improvement in albumen quality in response to 10 ppm dietary chromium. On the other hand 10 ppm vanadium results in dramatic loss in albumen quality. Such levels of vanadium can be contributed by contaminated sources of phosphates. Interestingly, the negative effect of vanadium is reported to be corrected by use of 10 ppm chromium in the diet.

4.9 Diet involvement with some general management problems

i) Hysteria -

Although not widespread in commercial flocks, hysteria can be a very serious nuisance and economic cost factor if encountered in a flock. Hysteria is easy to distinguish from an ordinary flighty flock, as the birds seem to lose all normal social behaviour and sense of direction and will mill and fly in every direction making unusual crying and squawking sounds. Birds often go into a molt, and then egg production declines. The condition of hysteria is more difficult to distinguish from flightiness in birds that are cage-reared rather than floor-reared. However, if one studies the flock for a period of time, differences can be seen.

The exact cause of hysteria is unknown, and attempts to artificially induce it in flocks have failed. Many people believe it is related to nutritional or environmental factors, or to a combination of both. Hysteria is more often encountered in birds 12 to 18 weeks of age; although it is sometimes also seen in older birds. Overcrowding is thought to be a factor in triggering the condition. Many drugs, feed supplements and management practices have been tried in an attempt to cure the condition with little or no success. Some people believe that it is a behavioral problem with the hens reacting to any noise or stimulus to which they are not accustomed. Why some flocks react differently to others is not known; however, it is well known

that small differences in various stressors result in markedly different responses in flocks. A number of diet modifications have been tried in an attempt to alleviate hysteria. These include high levels of methionine (2 kg/tonne), niacin (200 g/tonne supplement) or tryptophan (up to 5 kg/tonne supplement). The latter is thought to have a sedative-like effect by influencing brain neuro- transmitters. However, the response has been variable, and hysteria seems to return once tryptophan is withdrawn from the diet. In addition, until the price of tryptophan is reduced the treatment is prohibitively expensive. There is anecdotal evidence that adding meat meal or fish meal to a diet resolves the situation in birds fed all-vegetable diets.

ii) Prolapse - In the past, prolapse mortality of 2 to 3% per month over several months after housing pullets was not uncommon. Such losses were usually the result of a number of factors working together rather than any single problem. In most cases, the prolapse was due to picking rather than any physical stress resulting in 'classical prolapse'. Some of the problems that can lead to pickouts or blowouts are as follows:

- lights too bright (or sunlight streaming into open-sided buildings)
- temperature too high (poor ventilation)
- improper beak trimming
- pullets carrying excess of body fat
- poor feathering at time of housing
- too early a light stimulation
- too high protein/amino acid level in the diet causing early large egg size in relation to body and frame size

The condition is usually more severe with larger cage size groups and is a factor of floor space per bird rather than bird density. Frequently the incidence of picking has been shown to be higher in multiple bird cages where there is in excess of 460 sq. cm. of space per bird. When birds are more confined, they do not seem to be as aggressive. One of the most effective ways of avoiding a problem is to reduce light intensity. Where rheostats are available, these should be adjusted to a sufficiently low level that picking or cannibalism is kept to a minimum. With better control and understanding of light programs today, prolapse and associated problems are more likely to occur later in the production cycle. Mortality of 0.1% per month due to prolapse is now considered problematic.

While this type of problem is aggravated by high light intensity as well as high stocking density and poor beak trimming, it is felt that one of the main factors triggering the condition is low body weight. Even if pullets mature at body weights recommended by the breeder, many of them are up to 100 g lighter than standard at peak production. This, we suspect, is because the pullet is maturing with a minimum of body reserves. The bird also has a low feed consumption as it has been conditioned on a feed intake near to maintenance just prior to commencement of lay and so hasn't been encouraged to develop a large appetite. The pullet is laying at 92-96% and thus utilizes her body reserves (fat) in order to maintain egg mass production. This smaller body weight bird is often more nervous and so more prone to picking. Under these conditions, the nutritional management program of pullets outlined earlier in this chapter should be followed.

Prolapse can sometimes be made worse by feeding high protein/amino acid diets to small weight pullets in an attempt to increase early egg size. Coupled with an aggressive step-up lighting program this often leads to more double yolk eggs and so greater incidence of prolapse and blowouts. Such pullets are often below standard weight at 12 – 14 weeks, and so any catch up

growth is largely as fat, which also accentuates the problem. Being underweight at 12 – 14 weeks usually means that they have reduced shank length, and because the long bones stop growing at this time, short shanks are often used as a diagnostic tool with prolapse problems in 22 – 34 week old pullets.

iii) Fatty Liver Syndrome **-** The liver is the main site of fat synthesis in the bird, and so a 'fatty' liver is quite normal. In fact, a liver devoid of fat is an indication of a non-laying bird. However, in some birds, excess fat accumulates in the liver and this fat can oxidize causing lethal hemorrhages. Excess fat accumulation can only be caused by a surfeit of energy relative to needs for production and maintenance. Low protein, high-energy diets, and those in which there is an amino acid imbalance or deficiency can be major contributors to a fatty liver condition in layers. It is known that diets low in lipotrophic factors such as choline, methionine, and vitamin B_{12} can result in fatty infiltration of the liver. However, these nutrients are seldom directly involved in most of the fatty liver problems reported from the field. Excessive feed intake and more specifically high energy intake is the ultimate cause of the condition. It is well known that laying hens will over-consume energy, especially with higher energy diets and this is particularly true of high producing hens. Pullets reared on a feeding program that tends to develop a large appetite or encourages 'over-eating' (high fiber diets or skip-a-day feeding), are often more susceptible to the condition when subsequently offered a high energy diet on a free-choice basis during lay. There is some information to suggest that daily fluctuations in temperature, perhaps affected by the season of the year, will stimulate hens to over-consume feed. Hence, it is important to attempt some type of feed or energy restriction program if feed intake appears to be excessive.

When fatty liver is a problem, adding a mixture of so-called 'lipotrophic factors' to the diet is often recommended. A typical addition may involve 60 mg $CuSO_4$; 500 mg choline; 3 µg vitamin B_{12} and 500 mg methionine per kg of diet. It should be emphasized that in many cases, the addition of these nutrients will not cure the problem. Increasing the level of dietary protein by 1 to 2% seems to be one of the most effective ways of alleviating the condition. However, such treatments do not work in all cases. Another treatment that may prove effective is to increase the supplemental fat content of the diet. This apparently contradictory move is designed to offer the birds a greater proportion of energy as fat rather than carbohydrate. The idea behind this diet manipulation is that by reducing carbohydrate load there is less stress on the liver to synthesize new fat required for egg yolk production. By supplying more fat in the diet, the liver merely has to rearrange the fatty acid profile within fats, rather than synthesize new fat directly. For this treatment to be effective, the energy level of the diet should not be increased, the recommendation merely being substitution of carbohydrate with fat. This concept may be the reasoning for apparent effectiveness of some other treatments for fatty liver syndrome. For example, substitution of barley or wheat for corn has been suggested and this usually entails greater use of supplemental fat with these lower energy ingredients. Similarly, substitution of soybean meal with canola or sunflower meals usually means using more supplemental fat if energy level of the diet is to be maintained.

More recent evidence suggests that mortality is caused by eventual hemorrhaging of the liver and that this is accentuated or caused by oxidative rancidity of the accumulated fat. On this basis, we have seen a response to adding various antioxidants, such as ethoxyquin and vitamin E.

Adding ethoxyquin at 150 mg/kg diet and extra vitamin E at 50 – 60 IU/kg has been shown to reduce the incidence of hemorrhage mortality.

Experience has shown that it is difficult to increase production in a flock once the condition is established. Thus, it is important that a proper program be followed to prevent the development of fatty livers. In some cases, the cause of the trouble can be traced back to pullets coming into the laying house carrying an excess of body fat. If these birds are then fed a diet in which the balance of protein and energy is slightly suboptimal for a particular strain of bird, a buildup of fat in the liver may occur. In addition, the feeding of crumbles or pellets in the laying house may aggravate this condition since the hen may overconsume energy. The results of an experiment studying effects of the level of dietary protein on percent liver fat are shown in Table 4.43.

These older birds were all laying at a reasonable level and no Fatty Liver Syndrome problems were reported. As can be noted, all birds had livers high in fat. This is perfectly normal for a good laying bird and thus should not be confused with the Fatty Liver Syndrome where liver hemorrhage is the condition that usually kills the hen.

Recent information suggests that a condition similar to the so-called Fatty Liver Syndrome may be caused by certain types of molds or mold toxins. Although no definite relationship has been established to date between molds and fatty livers, care should be taken to ensure that molds are not a factor contributing to poor flock performance. Periodically canola meal has been implicated with the Fatty Liver Syndrome. While there were earlier reports with some of the high glucosinolate rapeseed meals triggering such a condition, there is no evidence to suggest that canola varieties are a factor in the fatty liver condition. Hemorrhage due to feeding rapeseed is usually not associated with excess fat infiltration of the liver.

iv) Cage Layer Fatigue - As its name implies, Cage Layer Fatigue (CLF) is a syndrome most commonly associated with laying hens held in cages, and so its first description in the mid 1950's coincides with the introduction of commercial cage systems. Apart from the cage environment, CLF also seems to need a high egg output to trigger the condition, and for this reason it has traditionally been most obvious in White Leghorns. At around the time of peak egg output, birds become lame, and are reluctant to stand in the cage. Because of the competitive nature of the cage environment, affected birds usually move to the back area of the cage, and death can occur due to dehydration/starvation because of their reluctance to drink or eat.

Table 4.43 Influence of dietary protein on liver fat

Dietary protein level (%)	*Egg production (HDB) (%)*	*Feed (g/d)*	*Liver fat (dry weight basis) (%)*
13	*76.4*	*108*	*49.3*
15	*77.0*	*107*	*40.2*
17	*78.0*	*107*	*38.2*

The condition is rarely seen in litter floor managed birds and this leads to the assumption that exercise may be a factor. In fact, removing CLF birds from the cage during the early stage of lameness and placing them on the floor usually results in complete recovery. However, this practice is usually not possible in large commercial operations. In the 1960 – 70's, up to 10% mortality was common, although now the incidence is considered problematic if 0.5% of the flock is affected. There is no good evidence to suggest an association of CLF to general bone breakage in older layers, although the two conditions are often described as part of the same general syndrome.

If birds are identified early, they appear alert and are still producing eggs. The bones seem fragile and there may be broken bones. Dead birds may be dehydrated or emaciated, simply due to the failure of these birds to eat or drink. The ribs may show some beading although the most obvious abnormality is a reduction in the density of the medullary bone trabeculae. Paralysis is often due to fractures of the fourth and fifth thoracic vertebrae causing compression and degeneration of the spinal cord. If birds are examined immediately after the paralysis is first observed, there is often a partly shelled egg in the oviduct, and the ovary contains a rich hierarchy of yolks. If birds are examined some time after the onset of paralysis, then the ovary is often regressed, due to reduced nutrient intake.

CLF is obviously due to an inadequate supply of calcium available for shell calcification, and the bird's plundering of unconventional areas of its skeleton for such calcium. Because calcium metabolism is affected by the availability of other nutrients, the status of phosphorus and vitamin D_3 in the diet and their availability are also important. Birds fed diets deficient in calcium, phosphorus or vitamin D_3 will show Cage Layer Fatigue assuming there is a high egg output.

Calcium level in the prelay period is often considered in preventative measures for CLF. Feeding low calcium (1%) grower diets for too long a period or even 2% calcium prelay diets up to 5% egg production often leads to greater incidence of abnormal bone development. It has been suggested that the resurgence in cases of CLF in some commercial flocks may be a result of too early a sexual maturity due to the genetic selection for this trait coupled with early light stimulation. Feeding a layer diet containing 3.5% Ca vs a grower diet at 1% Ca as early as 14 weeks of age has proven beneficial in terms of an increase in the ash and calcium content of the tibiotarsus (Table 4.44).

Table 4.44 Diet calcium and bone characteristics of young layers in response to prelay diet calcium

Time of change to	*Tibiotarsus*	
3.5% Ca (wk)	*Ash (%)*	*Ca (mg/g)*
20	53.5^c	182^b
18	55.7^b	187^b
17	59.3^a	202^a
16	58.9^a	199^a
15	58.9^a	197^a

Adapted from Keshavarz (1989)

Feeding a high calcium diet far in advance of maturity seems unnecessary, and in fact, may be detrimental in terms of kidney urolithiasis. Change from a low to a high calcium diet should coincide with the observation of secondary sexual characteristics, and especially comb development, which usually precedes first oviposition by 14 – 16 d.

We recently observed CLF in a group of individually caged Leghorns. The birds were 45 weeks of age and all fed the same diet. Within a 10 d period, 5% of the birds had CLF, and feed analyses showed adequate levels of calcium and phosphorus. The only common factor was an exceptionally high egg output for these affected birds. All these birds averaged 96% production from 25 – 45 weeks of age, and all had individual clutch lengths of 100 eggs. One bird had a clutch length of 140 eggs (i.e. 100% production). Their sisters in adjacent cages fed the same diet and without CLF, had maximum clutch lengths of 42 eggs in this period, and average production closer to 90%. These data suggest that in certain situations CLF is correlated with exceptionally high egg output.

There have been surprisingly few reports on the effect of vitamin D_3 on CLF in young birds. It is assumed that D_3 deficiency will impair calcium utilization, although there are no reports of testing graded levels of this nutrient as a possible preventative treatment. The other major nutrient concerned with skeletal integrity is phosphorus, and as expected, phosphorus deficiency can accentuate effects of CLF. While P is not directly required for shell formation, it is essential for the replenishment of Ca, as $CaPO_4$, in medullary bone during periods of active bone calcification. Without adequate phosphorus in the diet, there is a failure to replenish the medullary Ca reserves, and this situation can accelerate or precipitate the onset of CLF and other skeletal problems. Low phosphorus intake is sometimes caused by the trend towards lower levels of diet phosphorus coupled with very low feed intake of pullets through early egg production. For strains susceptible to CLF, then at least 0.5% available phosphorus is recommended in the first layer diet to be fed up to 28 – 30 weeks of age.

v) Bone breakage in older hens - CLF may relate to bone breakage in older hens, although a definitive relationship has never been verified. It is suspected that like the situation of CLF with young birds, bone breakage in older birds results as a consequence of inadequate calcification of the skeleton over time, again related to a high egg output coupled with the restricted activity within the cage environment. Few live birds have broken bones in the cage, the major problem occurring when these birds are removed from their cages and transported for processing. Apart from the obvious welfare implications, broken bones prove problematic during the mechanical deboning of the muscles.

Adding more calcium to the diet of older layers does not seem to improve bone strength, although this can lead to excessive eggshell pimpling. Adding both calcium and phosphorus to the diet has given beneficial results in some instances, although results are quite variable. In young birds at least, adding 300 ppm fluorine to the water has improved bone strength, although there are no reports of such treatment with end of lay birds. Moving birds from a cage to litter floor environment seems to be the only treatment that consistently improves bone strength. This factor indicates that exercise *per se* is an important factor in bone strength of caged birds, but does not really provide a practical solution to the problem at this time.

It is not currently known how to improve the bone integrity of older high producing hens

without adversely affecting other traits of economic significance. For example, it has been shown that bone breaking strength in older birds can be increased by feeding high levels of vitamin D_3. Unfortunately, this treatment also results in an excessive pimpling of the eggshells (as occurs with extra calcium) and these extra calcium deposits on the shell surface readily break off causing leakage of the egg contents. It may be possible to improve the skeletal integrity of older birds by causing cessation of ovulation for some time prior to slaughter. Presumably, the associated reduction in the drain of body calcium reserves would allow re-establishment of skeletal integrity. Currently such a feeding strategy is uneconomical, although consideration for bird welfare may provide the impetus for research in this area.

vi) Molting programs - Molting has come under scrutiny over the last few years, and in some countries, it is not allowed based on welfare issues. Undoubtedly, the most efficient way to molt birds, in terms of time and optimum second cycle production, is with light, water and feed withdrawal. It is the extensive period of feed withdrawal that raises welfare concerns even though mortality during this period is exceptionally low. With one molting, it is possible to prolong the production cycle to 90 weeks (52 + 40 weeks), while with two moltings the cycle can be 45 + 40 + 35 weeks. The productive life of the bird can therefore be doubled. When birds resume their second or third laying cycle, eggshell quality is almost comparable to that of 20-week-old birds, while even the first eggs produced will be large grade. Shell quality deteriorates more quickly in second and third cycles and this situation dictates the shorter cycles. The aim of a molting program is not necessarily to induce feather loss, but rather to shut down the reproductive system for a period of time. Generally the longer the pause in lay, the better the post-molt production. Egg pricing usually dictates the length of the molting period. If egg prices are high then a short molt period may be advantageous, whereas a longer molt period may ultimately be more economical when egg prices are low.

Examples of molt induced by feed withdrawal are shown in Table 4.45. With the type of programs shown in Table 4.45, one can expect birds to molt and to decline to near zero percent egg production. The lowest egg production will likely occur about 5 – 7 d after initiation of the program, and maximum feather loss will occur a week later than this. Programs should be adjusted depending upon individual flock circumstances. For example, under very hot weather conditions it would be inadvisable to withdraw water for extended periods of time. With a feed withdrawal program, body weight of the bird is one of the most important factors. Ideally, the body weight at the end of the first molt should be the same as the initial mature weight when the bird was 18 – 19 weeks of age. This effectively means that the molting program has to induce a weight loss equivalent to the weight gain achieved in the first cycle of lay.

Table 4.45 Molting with feed withdrawal

		White egg	Brown egg
1. Light			
	0 – 1 d	None	None
	1 – 40 d	8 hr or natural[1]	8 hr or natural[1]
	41d+	Step-up	Step-up
2. Water			
	0 – 1 d	None	None
	1 d+	Ad-lib	Ad-lib
3. Feed			
	0 – 7 d	None	None
	7 – 10 d	20 g cereal/d	25 g cereal/d
	10 – 20 d	45 g cereal/d	50 g cereal/d
	20 – 35 d	Pullet developer	Pullet developer
	35 d+	Layer II	Layer II
4. Body weight (kg)			
	1st cycle maturity	1.25	1.40
	End 1st cycle	1.60	1.75
	End 1st molt	1.35	1.50
	End of 2nd cycle	1.70	1.85

[1] provide 23 – 24 hr light/d for 5 d prior to start of molt

In reality this is difficult to achieve and a +100 g weight for second vs first cycle 'mature' weight is more realistic. Mortality is usually exceptionally low during the period of feed withdrawal, and in fact less than in the 4 – 8 week period prior to the molt. If mortality exceeds 0.1% per week, then it is cause for concern and perhaps a need for reintroducing feed. The actual period of feed withdrawal should be no more than 7 d, and ideally less than this if the desired weight loss is achieved.

The reduction in day length is a major stimulus to shutting down the ovary. While this is easily achieved in blackout houses, special conditions must be used with open-sided buildings. In order for the bird to be subjected to a significant step-down in daylength, then 5 – 7 d prior to the start of the molt, birds should be given 23 – 24 hr light each day. This means that with 16 hr natural light per day, removing the artificial light induces a significant reduction in day length which will help to reduce estrogen production.

Alternatives to feed withdrawal for molting are now being considered due to welfare issues. These alternative systems involve either high levels of minerals in conjunction with ad-lib feeding or the use of low nutrient dense diets/ingredients that are naturally less palatable. Considerable work has been conducted using high levels of dietary zinc, where up to 20,000 ppm causes a pause in lay, often without a classical molt, followed by resumption of production and fairly good second cycle production. Virtually all of this dietary zinc will appear in the manure, and so today there are environmental concerns regarding its disposal. Birds can also be molt-

ed by feeding diets deficient in sodium or chloride, although results tend to be quite variable with this system.

Using low nutrient density diets and ingredients seems to hold some promise for inducing a pause in lay. Dale and co-workers at Georgia have used diets with 50% cottonseed meal fed ad-lib, and recorded weight loss comparable to a feed withdrawal program. Birds fed this special diet lost 20% body weight within 10 d and egg production ceased after 5 d. Offering a diet containing 90% grape pomace also seems to work well in causing a dramatic decline in egg production. Adding thyroxine to the diet is also a potent stimulus to shutting down the ovary, although eggs produced by such birds contain elevated levels of thyroxine and so could not be marketed.

4.10 Nutrient management

Poultry manure is a valuble source of nitrogen, phosphorus and potassium for crop production. However, with the scale of layer farms today, the issue is the quantity of these nutrients produced within a small geographic location. The composition of manure is directly influenced by layer feed composition, and so higher levels of nitrogen in feed for example are expected to result in more nitrogen in the manure. One approach to reducing the problem of manure nutrient loading on farmland, is to reduce the concentration of these nutrients by altering feed formulation. Since this essentially entails reduction in feed nitrogen and phosphorus there are obviously lower limits for feed formulation such that production is not adversely affected. As a generalization, about 25% of feed nitrogen and 75% of feed phosphorus ends up in the manure. Also, layers will produce about as much manure (on a wet basis) as the feed eaten over a given period of time. The actual weight of manure is obviously greatly influenced by moisture loss both in the layer house and during storage. Table 4.46 shows average compositon of fresh cage layer manure.

The major issue today is loading of manure with nitrogen and phosphorus. Of these two nutrients, the level of nitrogen assayed in manure is the most variable since housing system and type of manure storage can have a dramatic effect on nitrogen loss as ammonia (Table 4.47).

Table 4.46 Composition of fresh cage layer manure

Moisture (%)	*70.0*
Gross energy (kcal/kg)	*250*
Crude Protein (%)	*8.0*
True Protein (%)	*3.0*
Nitrogen (%)	*1.2*
Uric acid (%)	*1.7*
Ash (%)	*8.0*
Calcium (%)	*2.2*
Phosphorus (%)	*0.6*
P_20_5 (%)	*1.3*
K_20 (%)	*0.6*
Sodium (%)	*0.1*
Fat (%)	*0.5*
NSP (%)	*10.0*
Crude Fiber (%)	*4.2*
Arginine (%)	*0.12*
Leucine (%)	*0.18*
Lysine (%)	*0.11*
TSAA (%)	*0.10*
Threonine (%)	*0.12*
Tryptophan (%)	*0.10*

Table 4.47 Nitrogen loss as ammonia for 10,000 layers per year (kg)

Total nitrogen excretion into manure	*7200*
Average house NH_3 loss	*-660*
Average storage NH_3 loss	*-120*
Average land NH_3 loss	*-1140*
Total nitrogen loss as ammonia	*-1920*
Total nitrogen available for crops	*5280*
Variable losses:	
a) Housing system:	
Liquid deep pit	*680*
High-rise solid	*290*
Belt, force drying	*290*
Deep litter	*1470*
b) Storage system:	
Belt drying	*410*
Lagoon	*3870*
c) Application system:	
Dry	*710*
Slurry	*1740*

Adapted from Van Horne et al. (1998)

Most of the nitrogen excreted by the bird relates to undigested material and those amino acids that are imbalanced with respect to immediate needs for tissue or egg synthesis. Nitrogen excretion can, therefore, be dramatically reduced by supplying a balance of amino acids that more exactly meets the bird's needs with minimum of excess, and also by providing these amino acids in a readily digested form. With methionine, lysine, and threonine now available at competitive prices, it is possible to formulate practical diets that provide a minimum excess of amino acids and non-protein nitrogen. Unfortunately, we seem unable to take this approach to its logical conclusion and formulate diets with very low levels of crude protein that contain regular levels of essential amino acids. At some point in the reduction of crude protein, we seem to lose growth rate or egg production/egg size which suggests that either we have reached the point at which non-essential amino acids become important, or that we have inadequately described the bird's amino acid needs or that the synthetic amino acids are not being used with expected efficiency. Of these factors, the need to more adequately describe amino acid needs under these specific formulation procedures is probably most important. However, we can readily reduce crude protein supply by 15 – 20% if the use of synthetic amino acids is economical or if there is a cost associated with the disposal of manure nutrients. The expected reduction in nitrogen output relative to diet crude protein in shown in Figure 4.20. As previously described, we cannot use extremely low protein levels without reduction in performance. For example, in the study in Figure 4.20, reducing CP from 17 to 13% resulted in a 2 g loss in egg size. Currently we can probably reduce protein levels to 14 – 15% for older layers. However, a 5% reduction in crude protein from 19% to 14% means a reduction in nitrogen output of about 2 tonnes per year for 10,000 layers.

Manure phosphorus levels are more easily predicted, since there is no subsequent loss once the manure is produced. As expected, manure phosphorus level is largely a factor of diet phosphorus level. Because phosphorus is an expensive nutrient, it tends not to be overformulated, however, there is usually some potential to reduce levels. Most of the manure phosphorus is undigested phytate phosphorus from the major feed ingredients such as corn and soybean meal. The phytate level in corn and soybean is variable and so this results in some variance in phosphorus in the manure. Table 4.48 shows the range of phosphorus in corn and soybean samples from Ontario, Canada.

Fig. 4.20 Nitrogen intake and excretion of layers in relation to diet protein level.

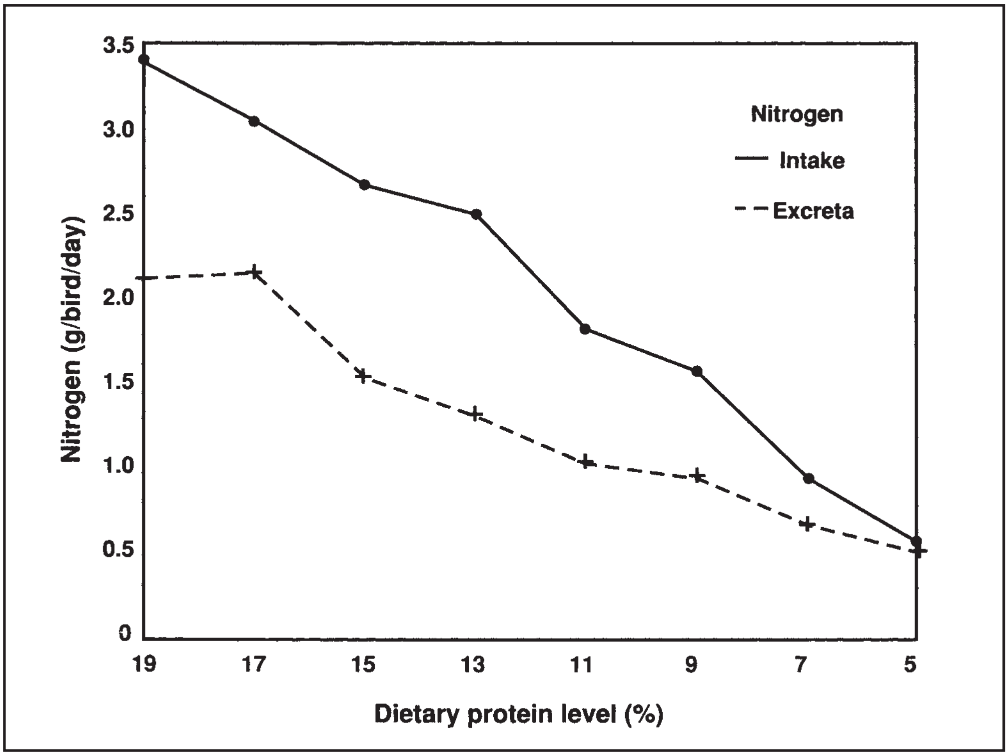


Table 4.48 Phosphorus content of corn and soybean meal[1]

	Average	*Lowest 15%*	*Highest 15%*
Corn:			
Samples tested	*198*	*30*	*30*
Average P (%)	*0.31*	*0.26*	*0.36*
Minimum P (%)		*0.24*	*0.34*
Maximum P (%)		*0.28*	*0.40*
Soybean meal:			
Samples tested	*106*	*16*	*16*
Average P (%)	*0.70*	*0.53*	*0.88*
Minimum P (%)		*0.43*	*0.80*
Maximum P (%)		*0.59*	*1.00*

[1] *adjusted from analysis of soybeans assuming 20% fat content* *Adapted from Leach (2002)*

Table 4.49 Hectares of corn land required for manure disposal from 10,000 layers/yr

Diet CP (%)	*Hectares*	*Diet P (%)*	*Hectares*
20	*47*	*0.55*	*45*
19	*45*	*0.50*	*40*
18	*44*	*0.45*	*36*
17	*41*	*0.40*	*32*
16	*40*	*0.35*	*28*
15	*37*	*0.30*	*23*
14	*35*	*0.25*	*19*

A corn-soy diet containing ingredients from the highest 15% vs lowest 15% grouping of phosphorus content is expected to increase manure phosphorus content by 20 – 25%.

Phytase enzyme now allows for significant reduction in diet phosphorus levels (25 – 30%) and this relates to a corresponding reduction in manure phosphorus levels. For more details on phytase, see Section 2.3 g.

Although there are lower limits to protein and phosphorus levels in layer diets, phase feeding programs involving the sequential reductions in N and P content of layer feed over time will have a meaningful effect on manure nutrient loading. Table 4.49 shows the land base required for 10,000 layers per year assuming that the land is used to grow corn and fertilizer rate is 140 kg N/hectare and 40 kg P/hectare. As CP level of the diet decreases from 20 to 14%, the land base required to adequately use the manure is reduced by 25%. With phosphorus there is potential reduction of 50% in land based relative to diet P levels used in formulation.

In the future, we may have to re-evaluate the levels of trace minerals fed to layers, since manure concentration of zinc and copper may come under closer scrutiny regarding soil accumulation.

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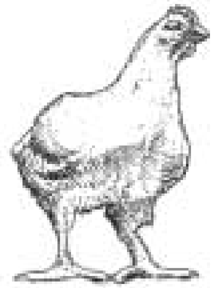
FEEDING PROGRAMS FOR BROILER CHICKENS

CHAPTER 5



5.1 Diet specifications and feed formulation

Genetic selection for growth rate continues to result in some 30-50 g yearly increase in 42-49 d body weight. There has also been an obvious improvement in feed efficiency and reduction in the incidence of metabolic disorders over the last 5 years, and so these changes have dictated some changes in feed formulation and feed scheduling. The modern broiler chicken is however, able to respond adequately to diets formulated over a vast range of nutrient densities. If there is no concern regarding classical measures of feed efficiency, then the highest nutrient dense diets are not always the most economical.

To a large extent, the ability of the broiler to grow well with a range of diet densities relates to its voracious appetite, and the fact that feed intake seems to be governed by both physical satiety as well as by cues related to specific nutrients. For example, varying the energy level of a broiler diet today has much less of an effect on feed intake, as expected on the basis of appetite being governed by energy requirement. This apparently subtle change in bird appetite has led to increased variability in diet type and diet allocation used by commercial broiler growers. However, as will be discussed later, attempting to 'cheapen' broiler diets through the use of lower protein/amino acid levels, while not having major effects on gross performance, leads to subtle changes in carcass composition. Feed programs may, therefore, vary depending upon the goals of the producer versus the processor.

Another major change in broiler nutrition that has occurred over the last 5 years is the realization that maximizing nutrient intake is not always the most economical situation, at least for certain times in the grow-out period. A time of so-called 'undernutrition', which slows down early growth rate appears to result in reduction in the incidence of metabolic disorders such as Sudden Death Syndrome and the various skeletal abnormalities. A period of slower initial growth, followed by 'compensatory' growth is almost always associated with improved feed efficiency, because less feed is directed towards maintenance. As increasing numbers of broilers are grown in hot climates, an understanding of the bird's response to temperature, humidity and photoperiod is becoming more important.

Diet specifications are shown in Tables 5.1, 5.2 and 5.3. Table 5.1 shows relatively high nutrient dense diets, while Table 5.2 indicates an alternate program for low nutrient dense diets. The choice of such feeding programs is often dictated by strain of broiler, environmental temperature and the relative cost of major nutrients such as energy and protein. Within these feeding programs a common vitamin-mineral premix is used, albeit at different levels, according to bird age. Because birds will eat more of the low vs. high nutrient dense diets, there is potential to reduce the premix nutrient levels by up to 10% for Table 5.2 vs. Table 5.1. When broilers are grown to very heavy weights (63 d+) then there is an advantage to using lower nutrient dense diets (Table 5.3). Tables 5.4 – 5.7 show examples of high nutrient dense diets appropriate for the specifications shown in Table 5.1. There are six variations of diets for the starter, grower, finisher and withdrawal periods. The diets differ in the major cereal used namely corn, sorghum or wheat, and with or without meat meal as another option.

Table 5.1 High nutrient density diet specifications for broilers

Approximate age	*0-18d Starter*	*19-30d Grower*	*31-41d Finisher*	*42d+ Withdrawal*
Crude Protein (%)	22	20	18	16
Metabolizable Energy (kcal/kg)	3050	3100	3150	3200
Calcium (%)	0.95	0.92	0.89	0.85
Available Phosphorus (%)	0.45	0.41	0.38	0.36
Sodium (%)	0.22	0.21	0.2	0.2
Methionine (%)	0.5	0.44	0.38	0.36
Methionine + Cystine (%)	0.95	0.88	0.75	0.72
Lysine (%)	1.3	1.15	1.0	0.95
Threonine (%)	0.72	0.62	0.55	0.5
Tryptophan (%)	0.22	0.2	0.18	0.16
Arginine (%)	1.4	1.25	1.1	1.0
Valine (%)	0.85	0.66	0.56	0.5
Leucine (%)	1.4	1.1	0.9	0.8
Isoleucine (%)	0.75	0.65	0.55	0.45
Histidine (%)	0.4	0.32	0.28	0.24
Phenylalanine (%)	0.75	0.68	0.6	0.5
Vitamins (per kg of diet)	100%	80%	70%	50%
Vitamin A (I.U)	8000			
Vitamin D_3 (I.U)	3500			
Vitamin E (I.U)	50			
Vitamin K (I.U)	3			
Thiamin (mg)	4			
Riboflavin (mg)	5			
Pyridoxine (mg)	4			
Pantothenic acid (mg)	14			
Folic acid (mg)	1			
Biotin (µg)	100			
Niacin (mg)	40			
Choline (mg)	400			
Vitamin B_{12} (µg)	12			
Trace minerals (per kg of diet)	100%	80%	70%	50%
Manganese (mg)	70			
Iron (mg)	20			
Copper (mg)	8			
Zinc (mg)	70			
Iodine (mg)	0.5			
Selenium (mg)	0.3			

Table 5.2 Low nutrient density diet specifications for broilers

Approximate age	***0-18d Starter***	***19-30d Grower***	***31-41d Finisher***	***42d+ Withdrawal***
Crude Protein (%)	21	19	17	15
Metabolizable Energy (kcal/kg)	2850	2900	2950	3000
Calcium (%)	0.95	0.9	0.85	0.8
Available Phosphorus (%)	0.45	0.41	0.36	0.34
Sodium (%)	0.22	0.21	0.19	0.18
Methionine (%)	0.45	0.4	0.35	0.32
Methionine + Cystine (%)	0.9	0.81	0.72	0.7
Lysine (%)	1.2	1.08	0.95	0.92
Threonine (%)	0.68	0.6	0.5	0.45
Tryptophan (%)	0.21	0.19	0.17	0.14
Arginine (%)	1.3	1.15	1.0	0.95
Valine (%)	0.78	0.64	0.52	0.48
Leucine (%)	1.2	0.9	0.8	0.75
Isoleucine (%)	0.68	0.6	0.5	0.42
Histidine (%)	0.37	0.28	0.25	0.21
Phenylalanine (%)	0.7	0.65	0.55	0.46
Vitamins (per kg of diet)	100%	70%	60%	40%
Vitamin A (I.U)	8000			
Vitamin D_3 (I.U)	3500			
Vitamin E (I.U)	50			
Vitamin K (I.U)	3			
Thiamin (mg)	4			
Riboflavin (mg)	5			
Pyridoxine (mg)	4			
Pantothenic acid (mg)	14			
Folic acid (mg)	1			
Biotin (µg)	100			
Niacin (mg)	40			
Choline (mg)	400			
Vitamin B_{12} (µg)	12			
Trace minerals (per kg of diet)	100%	70%	60%	40%
Manganese (mg)	70			
Iron (mg)	20			
Copper (mg)	8			
Zinc (mg)	70			
Iodine (mg)	0.5			
Selenium (mg)	0.3			

Table 5.3 Diet specifications for very heavy broilers

Approximate age	*0-15d Starter*	*16-30d Grower #1*	*31-45d Grower #2*	*46-56d Finisher #1*	*57d+ Finisher #2*
Crude Protein (%)	20	19	18	16	15
Metabolizable Energy (kcal/kg)	2850	2900	2950	3000	3000
Calcium (%)	0.95	0.9	0.85	0.8	0.75
Available Phosphorus (%)	0.45	0.41	0.36	0.34	0.3
Sodium (%)	0.22	0.21	0.19	0.18	0.18
Methionine (%)	0.42	0.38	0.33	0.30	0.28
Methionine+cystine (%)	0.85	0.76	0.68	0.66	0.64
Lysine (%)	1.13	1.02	0.95	0.92	0.90
Threonine (%)	0.64	0.56	0.47	0.42	0.39
Tryptophan (%)	0.20	0.18	0.16	0.13	0.11
Arginine (%)	1.22	1.08	0.94	0.89	0.85
Valine (%)	0.73	0.60	0.49	0.45	0.42
Leucine (%)	1.13	0.85	0.75	0.71	0.67
Isoleucine (%)	0.64	0.56	0.47	0.39	0.35
Histidine (%)	0.35	0.26	0.24	0.20	0.18
Phenylalanine (%)	0.66	0.61	0.52	0.43	0.39
Vitamins (per kg of diet)	100%	80%	70%	60%	40%
Vitamin A (I.U)	8000				
Vitamin D_3 (I.U)	3500				
Vitamin E (I.U)	50				
Vitamin K (I.U)	3				
Thiamin (mg)	4				
Riboflavin (mg)	5				
Pyridoxine (mg)	4				
Pantothenic acid (mg)	14				
Folic acid (mg)	1				
Biotin (µg)	100				
Niacin (mg)	40				
Choline (mg)	400				
Vitamin B_{12} (µg)	12				
Trace minerals (per kg of diet)	100%	80%	70%	60%	40%
Manganese (mg)	70				
Iron (mg)	20				
Copper (mg)	8				
Zinc (mg)	70				
Iodine (mg)	0.5				
Selenium (mg)	0.3				

Table 5.4 Examples of high nutrient dense broiler starter diets

	1	2	3	4	5	6
Corn	533	559				
Wheat					568	597
Sorghum			523	542		
Wheat shorts	60	60	70	72	68	69
Meat meal		40		50		42
Soybean meal	342	295	334	281	283	230
Fat	28.7	21.0	37.0	33.5	45.3	38.0
DL-Methionine*	2.5	2.6	2.6	2.8	2.8	2.9
L-Lysine	0.8	0.9	0.4	0.3	1.1	1.1
Salt	4.4	3.9	4.6	3.9	3.9	3.3
Limestone	15.8	12.0	16.0	11.2	16.2	12.5
Dical Phosphate	11.8	4.6	11.4	2.3	10.7	3.2
Vit-Min Premix**	1	1	1	1	1	1
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	22	22	22	22	22	22
ME (kcal/kg)	3050	3050	3050	3050	3050	3050
Calcium (%)	0.95	0.95	0.95	0.95	0.95	0.95
Av Phosphorus (%)	0.45	0.45	0.45	0.45	0.45	0.45
Sodium (%)	0.22	0.22	0.22	0.22	0.22	0.22
Methionine (%)	0.61	0.62	0.56	0.57	0.60	0.61
Meth + Cystine (%)	0.95	0.95	0.95	0.95	0.95	0.95
Lysine (%)	1.3	1.3	1.3	1.3	1.3	1.3
Threonine (%)	0.93	0.91	0.86	0.84	0.82	0.80
Tryptophan (%)	0.30	0.30	0.30	0.29	0.32	0.31

** or eqivalent MHA*
*** with choline*

Table 5. 5 Examples of high nutrient dense broiler grower diets

	1	2	3	4	5	6
Corn	613	646				
Wheat					630	665
Sorghum			573	600		
Wheat shorts	31	30	60	64	64	65
Meat meal		50		52		53
Soybean meal	295	237	289	230	223	160
Fat	26	16.4	44	34	49	37.3
*DL-Methionine**	2.4	2.5	2.5	2.7	2.7	2.9
L-Lysine	0.8	0.8	0.3	0.2	1.1	1.1
Salt	4.2	3.5	4.2	3.7	3.6	2.8
Limestone	16	11.3	16	11.5	16.4	11.9
Dical Phosphate	10.6	1.5	10	0.9	9.2	
*Vit-Min Premix***	1.0	1.0	1.0	1.0	1.0	1.0
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	20	20	20	20	20	20
ME (kcal/kg)	3100	3100	3100	3100	3100	3100
Calcium (%)	0.92	0.92	0.92	0.92	0.92	0.92
Av Phosphorus (%)	0.41	0.41	0.41	0.41	0.41	0.41
Sodium (%)	0.21	0.21	0.21	0.21	0.21	0.21
Methionine (%)	0.58	0.59	0.53	0.54	0.57	0.58
Meth + Cystine (%)	0.88	0.88	0.88	0.88	0.88	0.88
Lysine (%)	1.15	1.15	1.15	1.15	1.15	1.15
Threonine (%)	0.85	0.83	0.78	0.76	0.73	0.7
Tryptophan (%)	0.27	0.26	0.27	0.26	0.29	0.28

** or eqivalent MHA*
*** with choline*

Table 5.6 Examples of high nutrient dense broiler finisher diets

	1	2	3	4	5	6
Corn	693	726				
Wheat					714	779
Sorghum			643	676		
Wheat shorts			50	50	50	23
Meat meal		50		50		50
Soybean meal	250	192	236	178	161	100
Fat	23.7	13.1	38.5	27.9	43	29.8
DL-Methionine*	1.7	1.8	1.8	2.0	2.0	2.2
L-Lysine	0.8	0.8	0.3	0.2	1.2	1.2
Salt	3.9	3.3	4	3.4	3.2	2.5
Limestone	16	11.3	16.3	11.5	16.5	11.3
Dical Phosphate	9.9	0.7	9.1		8.1	
Vit-Min Premix**	1.0	1.0	1.0	1.0	1.0	1.0
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	18	18	18	18	18	18
ME (kcal/kg)	3150	3150	3150	3150	3150	3150
Calcium (%)	0.89	0.89	0.89	0.89	0.89	0.89
Av Phosphorus (%)	0.38	0.38	0.38	0.38	0.38	0.38
Sodium (%)	0.2	0.2	0.2	0.2	0.2	0.2
Methionine (%)	0.48	0.49	0.42	0.43	0.47	0.48
Meth + Cystine (%)	0.75	0.75	0.75	0.75	0.75	0.75
Lysine (%)	1.0	1.0	1.0	1.0	1.0	1.0
Threonine (%)	0.78	0.76	0.69	0.67	0.63	0.78
Tryptophan (%)	0.25	0.23	0.24	0.23	0.27	0.25

* or eqivalent MHA
** with choline

Table 5.7 Examples of high nutrient dense broiler withdrawal diets

	1	2	3	4	5	6
Corn	745	783				
Wheat					772	812
Sorghum			695	728		
Wheat shorts			50	50	50	60
Meat meal		60		50		50
Soybean meal	196	127	181	123	100	27
Fat	25	12.6	40.4	30	45	34
DL-Methionine*	2.0	2.2	2.2	2.3	2.4	2.6
L-Lysine	2.2	2.2	1.7	1.6	2.7	2.7
Salt	3.9	3.1	4	3.4	3.1	2.3
Limestone	15.4	8.9	15.7	10.7	16	8.4
Dical Phosphate	9.5		9.0		7.8	
Vit-Min Premix**	1.0	1.0	1.0	1.0	1.0	1.0
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	16	16	16	16	16	16
ME (kcal/kg)	3200	3200	3200	3200	3200	3200
Calcium (%)	0.85	0.85	0.85	0.85	0.85	0.85
Av Phosphorus (%)	0.36	0.39	0.36	0.37	0.36	0.38
Sodium (%)	0.20	0.20	0.20	0.20	0.20	0.20
Methionine (%)	0.49	0.50	0.43	0.44	0.48	0.49
Meth + Cystine (%)	0.72	0.72	0.72	0.72	0.72	0.72
Lysine (%)	0.95	0.95	0.95	0.95	0.95	0.95
Threonine (%)	0.69	0.67	0.60	0.58	0.53	0.51
Tryptophan (%)	0.21	0.20	0.21	0.19	0.24	0.22

* or eqivalent MHA
** with choline

5.2 Feeding programs

a) General considerations

While nutrient requirement values and diet formulations are fairly standard worldwide, there is considerable variation in how such diets are scheduled within a feed program. Feed program is affected by strain of bird, as well as sex and market age or market weight. Other variables are environmental temperature, local disease challenge and whether the bird is sold live, as an intact eviscerated carcass, or is destined for further processing. Management factors such as stocking density, feed and water delivery equipment and presence or not of anticoccidials and growth promoters, also influence feed scheduling.

The underlying factors to such inputs for feed scheduling, often relate to their influence on feed intake. Predicting daily or weekly feed intake is therefore of great importance in developing feed programs. Table 5.8 outlines expected feed intake for male and female broilers to 63 and 56 d respectively. In the first 20 d of growth, male and female broilers eat almost identical quantities of feed, and growth is therefore comparable. After this time, the increased growth of the male is a consequence of increased feed intake. Ten years ago, age in days x 4 gave an estimate of daily feed intake. Today, this estimate no longer holds true, since growth rate and feed intake have increased. For a male broiler chicken, daily feed intake of starter, grower, finisher and withdrawal can be estimated by multiplying bird age in days by 4, 5, 4 and 3.5 respectively.

The major factor influencing choice of feed scheduling is market age and weight. As a generalization, the earlier that a bird is marketed, the more prolonged the use of starter and grower feeds. For heavier birds, the high nutrient dense starter and grower feeds are used for shorter periods of time. Feed schedules for male and female broilers are shown in Tables 5.9 and 5.10 respectively while Table 5.11 outlines data for mixed-sex birds.

Feed scheduling tends to be on the basis of feed quantity or according to bird age, and both of these options are shown in Tables 5.9-5.11. The withdrawal diet is used for 5-10 d depending on market age although it must be emphasized that scheduling of this diet is dictated by the minimum withdrawal time of specific antibiotics, growth promoters and/or anticoccidials, etc.

The need for strain-specific diets is often questioned. Tables 5.12-5.14 outline the nutrient requirements of the three major commercial strains currently used worldwide. Since it is prohibitively expensive for breeding companies to conduct research on defining needs of all nutrients for their strains at all ages, then their requirement values are often based on information collected from customers worldwide. The published requirement values (Tables 5.12 – 5.14) are therefore considered to be the most appropriate for the individual strains under most commercial growing conditions. With this in mind, there are no major differences in nutrient requirements for any specific strain. In reality, the nutrient needs and feeding program for a 42 d vs. 60 d Ross male are going to be much more different than are requirements of a 42 d Ross vs. 42 d Cobb bird.

Table 5.8 Feed intake of male and female broilers (g/bird)

Age (d)	Male		Female	
	Daily	Cum.*	Daily	Cum.
1	13	13	13	13
2	15	28	15	28
3	18	46	18	46
4	21	67	21	67
5	24	91	23	90
6	25	116	25	115
7	27	143	26	141
8	32	175	32	173
9	37	212	37	210
10	42	254	41	251
11	47	301	46	297
12	53	354	52	349
13	59	413	58	407
14	66	479	65	472
15	74	553	70	542
16	80	633	76	618
17	85	718	81	694
18	90	808	86	785
19	95	903	91	876
20	100	1003	96	972
21	105	1108	102	1074
22	110	1218	106	1180
23	115	1333	110	1290
24	120	1453	114	1404
25	125	1578	117	1521
26	129	1707	120	1641
27	133	1840	123	1764
28	137	1977	126	1890
29	141	2118	130	2020
30	145	2263	132	2152
31	149	2412	133	2285
32	155	2567	134	2419
33	159	2726	136	2555
34	163	2889	140	2695
35	167	3056	143	2838
36	170	3226	147	2981
37	172	3398	150	3131
38	174	3572	152	3283
39	176	3748	153	3436
40	178	3926	154	3590
41	180	4106	154	3744
42	182	4288	154	3898
43	184	4472	155	4053
44	185	4657	156	4209
45	186	4843	156	4365
46	187	5021	157	4522
47	188	5209	158	4680
48	189	5398	159	4839
49	190	5588	160	4999
50	191	5779	161	5160
51	192	5971	161	5321
52	193	6164	162	5483
53	194	6358	163	5646
54	195	6553	164	5810
55	196	6749	165	5975
56	197	6946	165	6140
57	198	7144		
58	199	7343		
59	200	7543		
60	201	7744		
61	202	7946		
62	203	8149		
63	204	8353		

* Cumulative

Table 5.9 Feed schedule for male broilers

Feed allocation (kg/bird)											
Age (d)	*Body Wt.(g)*	*F:G*	*Starter*		*Grower*		*Finisher*		*Withdrawal*		*Total Feed (kg)*
			(kg)	*(age)*	*(kg)*	*(age)*	*(kg)*	*(age)*	*(kg)*	*(age)*	
42	2435	1.74	0.75	0-17 d	2.45	18-36 d			1.00	37-42 d	4.24
43	2510	1.76	0.70	0-17 d	2.72	18-37 d			1.00	38-43 d	4.42
44	2585	1.78	0.65	0-16 d	2.95	17-38 d			1.00	39-44 d	4.60
45	2660	1.80	0.65	0-16 d	2.13	17-33 d	1.00	34-39 d	1.00	40-45 d	4.79
46	2735	1.82	0.60	0-16 d	1.88	17-31 d	1.50	32-40 d	1.00	41-46 d	4.98
47	2810	1.84	0.60	0-16 d	1.62	17-30 d	1.90	31-41 d	1.05	41-47 d	5.17
48	2885	1.86	0.60	0-16 d	1.41	17-28 d	2.30	29-42 d	1.05	43-48 d	5.37
49	2960	1.88	0.58	0-15 d	1.32	16-28 d	2.56	29-43 d	1.10	44-49 d	5.56
50	3030	1.90	0.56	0-15 d	1.55	16-29 d	2.55	30-44 d	1.10	45-50 d	5.76
51	3100	1.92	0.54	0-15 d	1.70	16-30 d	2.61	31-45 d	1.10	46-51 d	5.95
52	3170	1.94	0.52	0-15 d	1.80	16-30 d	2.73	31-46 d	1.10	47-52 d	6.15
53	3240	1.96	0.50	0-14 d	1.90	15-31 d	2.80	32-47 d	1.15	48-53 d	6.35
54	3310	1.98	0.48	0-14 d	1.95	15-31 d	2.97	32-48 d	1.15	49-54 d	6.55
55	3380	2.00	0.46	0-14 d	2.00	15-31 d	3.15	32-49 d	1.15	50-55 d	6.76
56	3450	2.02	0.44	0-13 d	2.10	14-32 d	3.28	33-50 d	1.15	51-56 d	6.97
57	3520	2.03	0.42	0-13 d	2.20	14-32 d	3.32	33-51 d	1.20	52-57 d	7.15
58	3590	2.04	0.40	0-13 d	2.30	14-33 d	3.44	34-52 d	1.20	53-58 d	7.32
59	3660	2.06	0.40	0-13 d	2.40	14-34 d	3.54	35-53 d	1.20	54-59 d	7.54
60	3730	2.08	0.40	0-13 d	2.50	14-34 d	3.64	35-54 d	1.20	55-60 d	7.76
61	3800	2.09	0.40	0-13 d	2.60	14-35 d	3.65	36-55 d	1.30	56-61 d	7.94
62	3870	2.11	0.40	0-13 d	2.70	14-35 d	3.75	36-55 d	1.30	56-62 d	8.14
63	3940	2.12	0.40	0-13 d	2.80	14-35 d	3.85	36-55 d	1.30	56-63 d	8.35

Table 5.10 Feed schedule for female broilers

Feed allocation (kg/bird)											
Age (d)	*Body Wt. (g)*	*F:G*	*Starter*		*Grower*		*Finisher*		*Withdrawal*		*Total Feed (kg)*
			(kg)	*(age)*	*(kg)*	*(age)*	*(kg)*	*(age)*	*(kg)*	*(age)*	
35	1642	1.73	0.5	0-14 d	1.66	15-30 d			0.68	31-35 d	2.84
36	1704	1.75	0.5	0-14 d	1.79	15-31 d			0.70	32-36 d	2.98
37	1765	1.77	0.5	0-14 d	1.89	15-32 d			0.73	33-37 d	3.12
38	1827	1.79	0.5	0-14 d	2.02	15-33 d			0.75	34-38 d	3.27
39	1888	1.82	0.48	0-13 d	2.20	14-34 d			0.78	35-39 d	3.44
40	1949	1.84	0.48	0-13 d	2.31	14-35 d			0.80	36-40 d	3.59
41	2012	1.86	0.45	0-13 d	2.47	14-36 d			0.82	37-41 d	3.74
42	2075	1.88	0.45	0-13 d	2.61	14-37 d			0.84	38-42 d	3.90
43	2135	1.90	0.45	0-13 d	2.75	14-38 d			0.86	39-43 d	4.06
44	2194	1.92	0.43	0-13 d	2.88	14-38 d			0.90	39-44 d	4.21
45	2252	1.94	0.43	0-13 d	2.48	14-36 d	0.50	37-39 d	0.95	40-45 d	4.37
46	2308	1.96	0.43	0-13 d	2.44	14-35 d	0.70	36-40 d	0.95	41-46 d	4.52
47	2363	1.98	0.41	0-13 d	2.37	14-35 d	0.90	36-41 d	1.00	42-47 d	4.68
48	2417	2.00	0.41	0-13 d	2.32	14-34 d	1.10	35-42 d	1.00	43-48 d	4.83
49	2470	2.02	0.41	0-13 d	2.28	14-34 d	1.30	35-43 d	1.00	44-49 d	4.99
50	2522	2.04	0.41	0-12 d	2.23	13-34 d	1.50	35-44 d	1.00	45-50 d	5.14
51	2573	2.06	0.40	0-12 d	2.15	13-33 d	1.70	34-44 d	1.00	45-51 d	5.30
52	2623	2.08	0.40	0-12 d	2.11	13-33 d	1.90	34-45 d	1.05	46-52 d	5.46
53	2672	2.10	0.40	0-12 d	2.06	13-32 d	2.10	33-46 d	1.00	47-53 d	5.61
54	2720	2.13	0.40	0-11 d	2.04	12-32 d	2.27	33-47 d	1.05	48-54 d	5.81
55	2770	2.16	0.30	0-11 d	2.02	12-31 d	2.56	32-48 d	1.10	49-55 d	5.98
56	2820	2.18	0.30	0-11 d	2.00	12-31 d	2.74	32-49 d	1.10	50-56 d	6.14

Table 5.11 Feed schedule for mixed-sex broilers

Feed allocation (kg/bird)

Age (d)	*Body Wt. (g)*	*F:G*	*Starter (kg)*	*Starter (age)*	*Grower (kg)*	*Grower (age)*	*Finisher (kg)*	*Finisher (age)*	*Withdrawal (kg)*	*Withdrawal (age)*	*Total Feed(kg)*
42	2255	1.81	0.60	0-16 d	2.53	17-36 d			0.92	37-42 d	4.08
43	2323	1.83	0.58	0-15 d	2.74	16-37 d			0.93	38-48 d	4.25
44	2360	1.85	0.54	0-15 d	2.92	16-38 d			0.95	39-44 d	4.37
45	2456	1.87	0.54	0-13 d	2.31	16-34 d	0.75	35-39 d	0.98	40-45 d	4.59
46	2521	1.89	0.52	0-15 d	2.16	16-33 d	1.10	35-40 d	0.98	41-46 d	4.76
47	2586	1.91	0.51	0-15 d	2.00	16-32 d	1.40	33-41 d	1.03	42-47 d	4.94
48	2651	1.93	0.51	0-15 d	1.87	16-31 d	1.70	32-42 d	1.03	43-48 d	5.12
49	2715	1.95	0.50	0-14 d	1.80	15-31 d	1.93	32-43 d	1.05	44-49 d	5.29
50	2776	1.97	0.49	0-14 d	1.89	15-31 d	2.03	32-44 d	1.05	45-50 d	5.47
51	2836	1.99	0.47	0-14 d	1.93	15-31 d	2.16	32-45 d	1.08	46-51 d	5.64
52	2896	2.01	0.46	0-14 d	1.96	15-32 d	2.32	33-46 d	1.08	47-52 d	5.82
53	2956	2.03	0.45	0-13 d	1.98	14-32 d	2.45	33-47 d	1.10	48-53 d	6.00
54	3015	2.06	0.44	0-13 d	2.00	14-32 d	2.62	33-48 d	1.13	49-54 d	6.21
55	3075	2.08	0.38	0-12 d	2.01	13-31 d	2.86	32-49 d	1.13	50-55 d	6.40
56	3135	2.10	0.35	0-12 d	2.06	13-32 d	3.01	33-50 d	1.13	51-56 d	6.58

Table 5.12 Diet specifications for 2.5 kg broilers

	Starter				Grower		
	Hubbard	**Ross**	**Cobb**		**Hubbard**	**Ross**	**Cobb**
ME (kcal/kg)	3000	3040	3023		3080	3140	3166
CP (%)	22.0	22.0	21.5		20.0	20.0	19.5
Ca (%)	0.95	1.0	0.90		0.90	0.90	0.88
Av P (%)	0.44	0.50	0.45		0.40	0.45	0.42
Na (%)	0.19	0.21	0.20		0.19	0.21	0.17
Methionine (%)	0.50	0.53	0.56		0.45	0.46	0.53
Meth + Cys (%)	0.90	0.97	0.98		0.83	0.85	0.96
Lysine (%)	1.25	1.35	1.33		1.15	1.18	1.25
Threonine (%)	0.81	0.87	0.85		0.75	0.70	0.80

Table 5.13 Diet specifications for 2.5 kg broilers

	Finisher				Withdrawal		
	Hubbard	**Ross**	**Cobb**		**Hubbard**	**Ross**	**Cobb**
ME (kcal/kg)	3150	3200	3202		3160	3220	3202
CP (%)	19.0	18.0	18.0		18.0	17.0	17.0
Ca (%)	0.87	0.85	0.84		0.82	0.76	0.78
Av P (%)	0.37	0.42	0.40		0.34	0.37	0.35
Na (%)	0.19	0.21	0.16		0.19	0.21	0.16
Methionine (%)	0.42	0.43	0.48		0.39	0.42	0.44
Meth + Cys (%)	0.80	0.80	0.88		0.75	0.79	0.88
Lysine (%)	1.05	1.09	1.10		0.93	1.03	1.04
Threonine (%)	0.72	0.72	0.73		0.69	0.70	0.70

Table 5.14 Vitamin-Mineral Premixes (starter or general)

	Hubbard	*Ross*	*Cobb*
Vitamin A (I.U)	7000	8270	12000
Vitamin D_3 (I.U)	3500	3030	4000
Vitamin E (I.U)	40	50	30
Vitamin K_3 (I.U)	2.2	2.2	4.0
Thiamin (mg)	4.0	2.4	4.0
Riboflavin (mg)	6.0	7.7	9.0
Pantothenate acid (mg)	11.0	12.7	
Niacin (mg)	45	51.8	
Pyridoxine (mg)	3.3	2.4	4.0
Choline (mg)	750	-	400
Folic acid (mg)	1.0	1.1	1.5
Biotin (µg)	100	110	150
Vitamin B_{12} (µg)	12	15.4	20
Manganese (mg)	66	120	120
Zinc (mg)	50	110	100
Iron (mg)	80	20	40
Copper (mg)	9.0	16	20
Iodine (mg)	1.0	1.25	1.0
Selenium (mg)	0.30	0.30	0.30

b) Prestarters

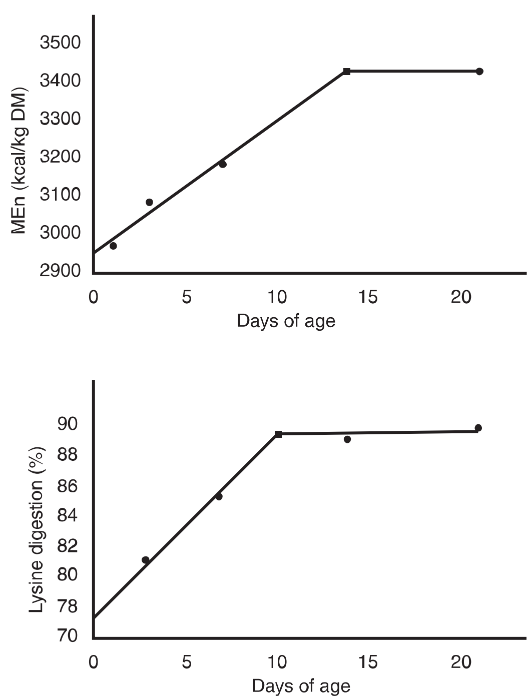
It is generally recognized that the neonate chick does not produce an adult complex of digestive enzymes, and so digestibility is somewhat impaired. This situation is further complicated by the change in nutrient substrate of lipid and protein in the embryo to quite complex carbohydrates, proteins and lipids in conventional starter diets. So even though chicks grow quite rapidly in the first few days of life, there is the idea that this could be further enhanced by use of a prestarter. Prestarters therefore, either pre-condition the chick such that it can digest complex substrates and/or provide more (or more highly digestible) substrates until the chick's enzyme production has 'matured'.

The role of the unabsorbed yolk sac in early life nutrition is open to debate. On an evolutionary scale the yolk sac likely provides a source of energy, water and perhaps, most importantly, IgA maternal antibodies for the young bird. Most altricial birds have virtually no yolk sac, while precocial birds have considerable yolk reserves at hatch. The yolk sac in chicks weighs around 8-10 g depending on the size of the original egg yolk. It is often stated that the residual yolk will be used more quickly if the chick is without feed and water. It seems that yolk utilization is unaffected by presence or not of feed with a linear decline in yolk weight up to 3 d post-hatch. By day 3, regardless of feed supply, yolk size is only around 2-3 g. During this time there is an

increase in enzyme supply within the intestinal lumen. Specific activity of individual enzymes actually declines over the first week of life, although this is compensated for by rapid increase in secretory cell numbers. Early cell damage, especially in the duodenum will greatly impair digestion.

While corn-soybean meal diets are regarded as ideal for poultry, there is evidence that digestibility is sub-optimal for the young chick. Parsons and co-workers show reduced AMEn and amino acid digestion in chicks less than 7-10 d of age (Figure 5.1).

Figure 5.1 Age effect on AMEn and lysine digestion of a corn-soy diet (Batal and Parsons, 2002)



With some 10% reduction in nutrient digestion compared to expected values, it is obvious that our conventional starter diets are not ideal for young chicks.

The idea in formulating prestarter diets is to correct any such deficiency, and so hopefully increase early growth rate and/or improve uniformity of such early growth. Two types of prestarter diets are used for broiler chickens. The first option is to use greater than normal levels of nutrients while the alternate approach is to use more highly digestible ingredients. According to Figure 5.1, if we increase nutrient supply by 10-15%, it should be possible to correct any deficiency in digestibility, and so realize expected AME_n and amino acid utilization. A potential problem with this approach is the acceptance that nutrients will not be optimally digested and that such undigested nutrients will fuel microbial overgrowth.

An alternate approach is to use more highly digestible ingredients, with little change in level of nutrients. Such prestarter diets are going to be very expensive, since alternative ingredients are invariably more expensive than are corn and soybean meal. Table 5.15 shows ingredients that could be considered in formulating specialized prestarter diets.

Using these ingredients, it is possible to achieve 190-200 g body weight at 7 d, compared to 150-160 g with conventional corn-soybean diets. This improved early growth rate continues during most of the subsequent grow-out period (Table 5.16).

In this study, male broilers were 34% heavier than standard, when a highly digestible prestarter was fed for the first 4 d. Because of the ingredients used in formulation, this prestarter was twice as expensive as the conventional corn-soy starter diet. As shown in Table 5.16, the advantage of using the prestarter diminishes with age, although birds were still significantly heavier at 42 d. Interestingly, the highly digestible prestarter had no effect on uniformity of body

Table 5.15 Potential ingredients for highly digestible prestarter diets

		Max. % inclusion
Cereals	*Rice*	40
	Corn	30
	Glucose (cerelose)	5
	Oat groats	5
Proteins	*Fish meal*	5
	Fish protein concentrate	5
	Blood plasma	10
	Casein	8
	Soybean meal	20
	Alfalfa	4
Fats	*Vegetable oil*	4
Additives	*Wheat enzyme*	
	Mannanoligosaccharide	
	Probiotic	
	Lactic acid	

Table 5.16 Effect of using a highly digestible prestarter to 4 d of age, on growth of male broilers

	Age (days)				
	4d	7 d	21 d	33d	42d
Prestarter (0-4 d)	117	190	820	1900	2670
Conventional	87	150	700	1700	2450
Difference	34%	21%	17%	12%	9%

(Swidersky 2002, unpublished data)

weight at any time during the trial. In this and other studies, we have seen no advantage to using so called 'mini-pellets' vs. using good quality fine crumbles.

c) Low nutrient dense diets

By offering low protein, low energy diets (Table 5.2) it is hoped to reduce feed costs. However, it is obvious that the birds will necessarily consume more of these diets and that birds may also take longer to reach market weight. These two factors result in reduced feed efficiency. Surprisingly, broiler chickens seem to perform quite reasonably with low nutrient dense diets, and in certain situations these may prove to be the most economical program. If diets of low

energy level are fed, the broiler will eat more feed (Table 5.17).

In this study, only the energy level was changed and the broiler adjusted reasonably well in an attempt to maintain constant energy intake. Diet energy from 3300 – 2700 kcal ME/kg had no significant effect on body weight, and this suggests the bird is still eating for its energy need. Obviously these data on growth rate are confounded with the intake of all nutrients other than energy. For example, birds offered the diet with 2700 kcal ME/kg increased their protein intake in an attempt to meet energy needs. Using these same diets, but controlling feed intake at a constant level for all birds (Table 5.18) shows that energy intake *per se* is a critical factor in affecting growth rate.

With low energy diets, therefore, we can expect slightly reduced growth rate because 'normal' energy intake is rarely achieved and this fact is the basis for programs aimed at reducing early growth rate. However, live body weight is often not the 'end-point' of consideration for broiler production, since carcass weight and carcass composition are often important. From the point of view of the processor or integrator, these cheaper diets may be less attractive. Carcass weight and meat yield are often reduced, and this is associated with increased deposition of carcass fat, especially in the abdominal region. Low protein diets are therefore less attractive when one considers feed cost/kg edible carcass or feed cost/kg edible meat. This consideration of carcass composition leads to development of diets that maximize lean meat yield.

Another concept for feeding broilers is true low nutrient dense diets, where all nutrient concentrations are reduced (in practice energy and protein/amino acids are most often the only

Table 5.17 Performance of broilers fed diets of variable energy content

	Body weight (g)		*Feed intake (g/bird)*		
Diet ME (kcal/kg)	***25 d***	***49 d***	***0 – 25 d***	***25 – 49 d***	***0 – 49 d***
3300	*1025*	*2812*	*1468*	*3003*	*4471*
3100	*1039*	*2780*	*1481*	*3620*	*5101*
2900	*977*	*2740*	*1497*	*3709*	*5206*
2700	*989*	*2752*	*1658*	*3927*	*5586*

Table 5.18 Performance of broilers given fixed quantities of feed

	Body weight (g)		*Feed intake: body weight gain*
Diet ME (kcal/kg)	***25 d***	***49 d***	***0 – 49 d***
3300	*825*[a]	*2558*[ab]	*1.84*[c]
3100	*818*[a]	*2599*[a]	*1.82*[c]
2900	*790*[b]	*2439*[b]	*1.94*[b]
2700	*764*[b]	*2303*[c]	*2.05*[a]

Table 5.19 Response of male broiler to low nutrient dense finisher diets (35 – 49 d)

Diet nutrients		*Body wt. (g)*		*Feed intake (g)*	*Carcass wt. (g)*	*Breast wt. (g)*
ME (kcal/kg)	***CP (%)***	***42 d***	***49 d***	***35 – 49 d***	***49 d***	***49 d***
3210	*18.0*	*2420*	*2948*	*2583*	*2184*	*418*
2890	*16.2*	*2367*	*2921*	*2763*	*2107*	*404*
2570	*14.4*	*2320*	*2879*	*2904*	*2063*	*400*
2250	*12.6*	*2263*	*2913*	*3272*	*2088*	*402*
1925	*10.8*	*2170*	*2913*	*3673*	*2073*	*390*
1605	*9.0*	*2218*	*2892*	*4295*	*2038*	*378*

nutrients changed in such a program). Examples of such diets are shown in Table 5.2. With this type of feeding program, one can expect slower growth and inferior feed efficiency, although this should not be associated with increased fat deposition. Depending upon local economic conditions and the price of corn and fat, this type of program can be economical.

The older the broiler chicken, the greater its ability to adapt to very low nutrient dense diets. When broilers are offered very low nutrient dense diets in the finisher period, they adapt quite well and growth rate is little affected (Table 5.19). In the 42-49 d period broilers adjusted almost perfectly to the low nutrient dense diets, and growth rate was maintained by adjustment to feed intake. With the lowest nutrient dense diet for example, which is at 50% of the control level of nutrients, broilers exactly doubled their feed intake. The reduction in carcass and breast weight is likely a reflection of reduced intake during the 35-42 d period of adjustment. It is not likely that 50% diet dilution is economical, yet the data in Table 5.19 indicates that the broiler is not eating to physical capacity, and given sufficient time for adjustment, can at least double its feed intake. In the 42-49 d period, broilers fed the diet of lowest nutrient density consumed over 300 g feed each day.

d) Growth restriction

Broilers are usually given unlimited access to high nutrient dense diets, or have

limited access during brief periods of darkness. It is generally assumed that the faster the growth rate, the better the utilization of feed, since maintenance nutrient needs are minimized

Figures 5.2 and 5.3 indicate the increase in genetic potential of the male broiler over the last 30 years. It is obvious that there has been major emphasis placed on early growth rate, since the modern broiler is now at least 300% heavier at 7 d compared to hatch weight, while 20 years ago. This value was closest to 200%.

However, fast initial growth rate can lead to management problems, such as increased incidence of metabolic disorders. Also, if early growth rate can be tempered without loss in weight-for-age at 42 – 56 d, then there should be potential for improved feed efficiency due to reduced maintenance needs. This concept is often termed compensatory gain.

Figure 5.2 Male Broiler Growth over the last 30 Years

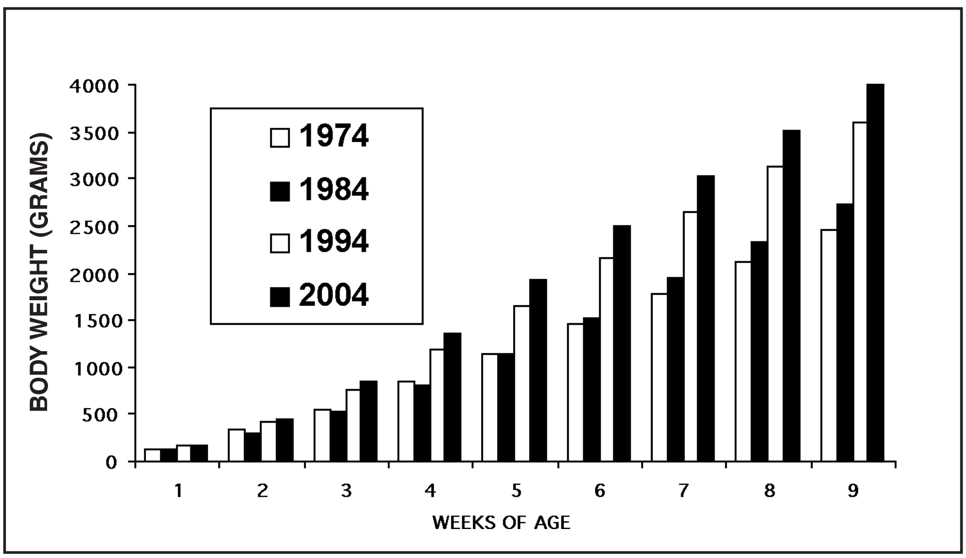
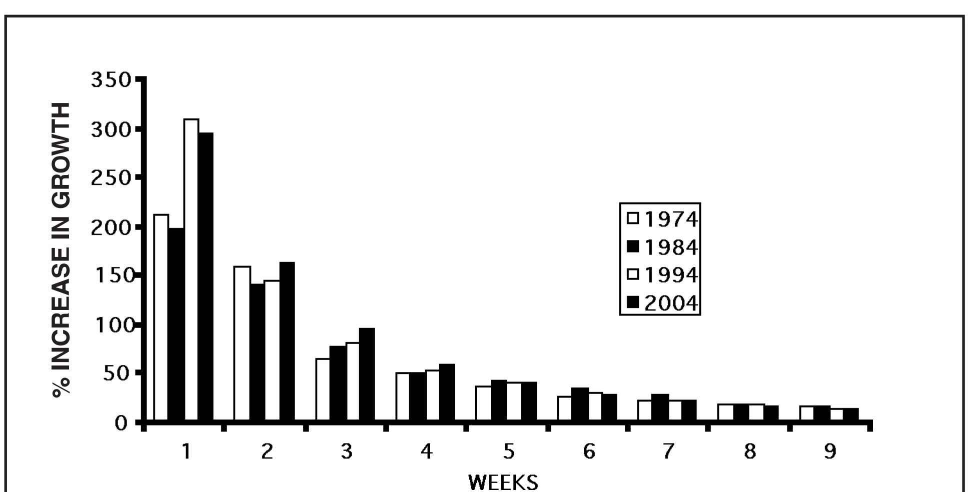


Figure 5.3 Percentage weekly increase in growth of male broilers.



If growth rate is to be reduced, then based on needs to optimize feed usage, nutrient restriction must occur early in the grow out period (Table 5.20). As the bird gets older, a greater proportion of nutrients are used for maintenance and less is used for growth. Therefore, reducing nutrient intake in, say the first 7 d, will have little effect on feed efficiency, because so little feed is going towards maintenance (Table 5.20). At 8 weeks of age, a feed restriction program would be more costly, because with say a 20% restriction there would likely be no growth, because 80% of nutrients must go towards maintenance. Early feed restriction programs therefore make sense from an energetic efficiency point of view, and are the most advantageous in programs aimed at reducing the incidence of metabolic disorders.

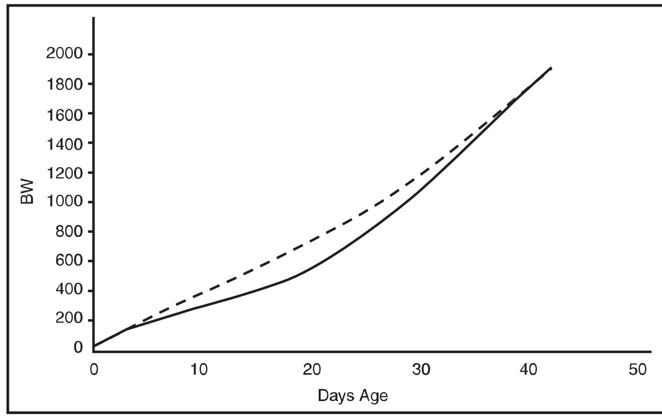
Table 5.20. Proportion of energy for growth vs. maintenance

	(%) Distribution	
Week	*Maintenance*	*Growth*
1	*20*	*80*
2	*30*	*70*
3	*40*	*60*
4	*50*	*50*
5	*60*	*40*
6	*70*	*30*
7	*75*	*25*
8	*80*	*20*

If birds grow more slowly in the first few weeks and achieve normal market weight for age, then the difference in the growth curves should be proportional to the reduction in maintenance energy needs. Figure 5.4 shows an example of compensatory growth in female broilers, achieved by feed restriction from 4 – 10 d of age.

If regular market weight-for-age is not achieved due to early life undernutrition, then benefits of improved feed efficiency are not realized. This situation often happens when the period of undernutrition is too prolonged, or the degree of undernutrition is too severe. A period of undernutrition can be achieved by physical feed restriction, diet dilution or by limiting access time to feed as occurs with some lighting programs (see section 5.5).

Figure 5.4 Compensatory growth curve exhibited by female broilers.



In early studies, we fed broiler chickens conventional starter diets to 4 days of age and then the same diet diluted with up to 55% rice hulls from 6 – 11 days. After this time, the conventional starter was reintroduced, followed by regular grower and finisher diets. Table 5.21 indicates the amazing ability of the broiler chicken to compensate for this drastic reduction in nutrient intake from 6 – 11 days of age.

When broilers are fed limited quantities of feed through to market age, there is a predictable reduction in growth rate (Table 5.22).

When there is continuous feed restriction, feed efficiency is compromised, since there is no potential for compensatory growth. When feed restriction is applied only during early growth, then there is potential for compensatory growth (Table 5.23).

Table 5.21 Effect of diet dilution with rice hulls from 6 – 11 days of age, on compensatory growth of male broiler chickens

Treatment	*Body weight (g)*				*Feed:gain*		*ME/kg gain*
	21 d	*35 d*	*42 d*	*49 d*	*21 – 35 d*	*0 – 49 d*	*0 – 49 d*
Control	733	1790	2390	2890	1.84	2.01	6.21
50% dilution 6-11 d	677	1790	2380	2950	1.70	1.93	5.90

Adapted from Zubair and Leeson (1994)

Table 5.22 Effect of 5 – 15% feed restriction from 1 – 42 d on broiler growth

Feeding system	*Body wt. (g)*	*F:G*	*Mortality (%)*	*Carcass wt. (g)*
Ad lib	2401^{a}	1.68	5.6^{b}	1849^{a}
5% restriction	2201^{b}	1.76	4.5^{ab}	1716^{b}
10% restriction	2063^{bc}	1.75	3.2^{ab}	1625^{bc}
15% restriction	1997^{c}	1.78	1.1^{b}	1518^{c}

Adapted from Urdaneta and Leeson (2002)

Table 5.23 Effect of feeding at 90% of *ad-lib* intake for various times, on growth and mortality of male broilers

	Body wt. (g)		*F:G*	*Mortality (%)*		
	35 d	*49 d*	*(0 – 49 d)*	*Total*	*SDS*	*Ascites*
Ad-lib	1744	2967	1.75	11.7	8.3	1.7
5 – 10 d[1]	1696	2931	1.71	8.3	4.9	1.7
5 – 15 d	1725	2934	1.69	8.3	3.3	1.7
5 – 20 d	1727	2959	1.70	8.3	4.9	1.7
5 – 25 d	1734	2947	1.69	8.3	4.9	1.7
5 – 30 d	1676	2875	1.69	5.1	1.6	0

[1]90% of ad-lib

With 10% feed restriction from 5 up to 25 days of age, there was minimal effect on growth rate, although feed efficiency was improved. This improvement in feed utilization is a consequence of reduced mortality and reduced maintenance need due to slower initial growth. When feed restriction occurs in the mid-period of growth (14 – 28 d) there is little effect on mortality and growth compensation is rarely achieved.

The results of early feed restriction or undernutrition on carcass composition are quite variable. The early work of Plavnik and co-workers suggested that feeding to maintenance energy needs from 4 – 11 d of age resulted in a marked reduction in carcass fatness and especially yield of the abdominal fat pad. The reasoning behind reduced fatness was limited early growth of adipose cells. We have not been able to consistently duplicate these results. However, in most studies, even when body weight compensation is achieved, there are often subtle reductions in carcass yield and especially breast meat yield.

A consistent result of early undernutrition is reduction in the incidence of metabolic disorders and especially SDS. Although such conditions are less problematic than 5 –10 years ago they often still represent the major cause of mortality and condemnations, and any reduction in mortality is of economic importance. It seems as though early undernutrition can be economical as long as final weight-for-age is not compromised.

A practical problem with diet dilution or feed restriction, is deciding on levels of anticoccidials and other feed additives. With diet dilution, birds will eat much more feed. If for example, feed intake is doubled due to a 50% dilution, should the level of anticoccidial be reduced by 50%? With 50% feed restriction on the other hand, does there need to be an increase in concentration of these additives? This general area needs careful consideration, and results may well vary with the chemical compounds under consideration due to potential toxicity at critical levels.

Where broilers are necessarily grown at high altitude or when birds are exposed to environmental temperatures of <15˚C, mortality due to ascites is inevitable. Although the breeding companies have selected against this condition, mortality of up to 10% is still common in male broilers grown under these adverse conditions. In these situations, mild feed restriction throughout rearing is often economical, where the 2 – 3 d longer growing period is offset by much lower mortality. Table 5.24 gives examples of mild and severe restriction programs for male broilers. Feed restriction can start as early as 3 – 4 d. Table 5.24 shows cumulative feed intake expected in the first week together with subsequent intakes each 2 d. The cumulative intake data takes into account the intake on the odd days not shown.

e) Heavy broilers/roasters

In relation to its mature weight, the broiler chicken is marketed at a relatively young age. At 49 – 56 d, growth rate of the male bird is still linear, even though maximum growth rate occurs at 5 – 6 weeks of age. Modern strains of male broilers are still able to increase their body weight by 450-500 g each week through to 11 or 12 weeks of age. The breast yield of these older birds is maintained, and so very heavy broilers or roasters find ready niche markets. The major challenge in growing these heavy birds is preventing high levels of mortality. In a recent study in which broilers were offered *ad-lib* feed to a mature weight of around 8 kg, 70% mortality occurred in the male birds.

Perhaps the most important consideration in growing heavy broilers is development of specialized feed programs that are not merely 'continuations' of conventional 0 - 49 d broiler programs. Table 5.3 provides examples of diets for heavy broilers grown to 60 – 70 d of age. There seems to be no need for high nutrient dense diets at any time during growout, and even single stage low-nutrient dense diets give reasonable results (Table 5.25).

Table 5.24 Examples of mild and severe feed restriction programs aimed at reducing incidence of metabolic disorders

Age (d)	Standard Program (g/b)		Severe Restriction (g/b)		Mild Restriction (g/b)	
	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative
8	34	184	31	171	32	174
10	49	274	44	252	46	258
12	58	387	49	351	55	365
14	72	524	61	467	66	491
16	81	680	69	600	75	636
18	91	857	77	750	85	801
20	100	1053	85	917	96	988
22	109	1266	98	1108	105	1193
24	118	1497	106	1316	115	1416
26	124	1743	112	1538	122	1658
28	132	2003	123	1776	130	1913
30	139	2277	129	2030	139	2187
32	147	2566	137	2299	147	2476
34	154	2871	146	2586	154	2781
36	159	3188	151	2887	159	3098
38	163	3512	155	3195	163	3422
40	167	3844	159	3510	167	3754
42	171	4184	162	3833	171	4094
44	173	4529	164	4161	173	4439
46	176	4880	167	4494	176	4790
48	180	5237	176	4844	180	5147

Table 5.25 Growth of male broilers to 70 d when fed diets of varying nutrient density

Diet CP:ME (%:kcal/kg)			Body wt (g)	F:G	Mortality (%)	Protein efficiency	Energy efficiency	Relative feed cost
0-21 d	**21 – 49 d**	**49 – 70 d**	**70 d**	**0 – 70 d**	**0 – 70 d**	**kg/kg gain**	**Mcal/kg gain**	**(per kg gain)**
20:3100	18:3100	16:3200	4193a	2.26b	19.2	0.39c	7.1ab	100
20:3100	18:2900	16:2800	4088ab	2.55a	16.7	0.44b	7.3ab	101
20:3100	18:2900	18:2900	4077ab	2.48a	16.7	0.45ab	7.2ab	97
20:3100	20:3100	20:3100	4046ab	2.40ab	12.5	0.48a	7.4a	105
18:2900	18:2900	18:2900	4260a	2.45ab	13.3	0.39c	6.9b	85
16:2800	16:2800	16:2800	3753b	2.45ab	10.8	0.39c	6.9b	85

Leeson et al. 2000

Only with the single diet of 16% CP at 2800 kcal ME/kg fed from 0 – 70 d was there reduced growth rate. In this study a single diet of 18% CP and 2800 kcal ME/kg appeared to be the most economical. Carcass yield and breast meat yield were not different for all but the 16% CP diet. As shown in Table 5.25, mortality declined as nutrient density declined, yet even with just 16% CP and 2800 kcal ME/kg there was over 10% mortality to 70 d. Regardless of diet nutrient density, we have been unable to reduce mortality below 10% without recourse to using mash diets. It seems as though regardless of nutrient density, the broiler is able to increase its intake of pelleted feed, and this undoubtedly contributes to high mortality. In order to reduce mortality this voracious appetite has to be controlled, and this can be achieved quite easily by offering mash, rather than pelleted diets (Table 5.26).

Table 5.26 Performance of male broilers to 70 d when fed mash vs. pellet diets

	Body Wt. 70 d (g)	*F:G*[3]	*Mortality (%)*
High density[1]			
Mash	3850	2.31	4.2
Pellets	4166	2.44	20.0
Low density[2]			
Mash	3571	2.45	5.8
Pellets	4111	2.50	12.5

1 20% CP:3100 Kcal/kg ME, starter (0-21 d);
18% CP:3100 Kcal/kg ME, grower (21-49 d);
16% CP:3200 Kcal/kg ME, finisher (49-70 d).
2 18% CP:2900 Kcal/kg ME (0-70 d)
3 Adjusted for mortality

Adapted from Leeson et al. 2000

Feeding high nutrient dense mash vs. pelleted diets reduced growth rate by about 300 g to 70 d, which represents just 2 – 3 d prolonged grow-out. At the same time mortality was reduced from 20% to 4%, and so feed efficiency was actually superior with the mash diet. With low nutrient dense diets growth rate is more greatly affected by using mash diets, where 70 d males are some 5 – 6 d behind schedule. Although there are logistical problems when using mash diets in mechanized feeders and microbial control may be more difficult, adapting feed texture seems to have great potential in growing very heavy male broilers.

f) Feed withdrawal

The current major concern about feed withdrawal relates to microbial contamination during processing. Regardless of withdrawal time, the gut will retain some digesta, and this can contaminate birds during transportation as well as the scald water during processing. Also if the intestines are broken during evisceration there is potential for contamination.

Withdrawing feed 6 – 8 hr prior to catching seems to be optimum in terms of the bird clearing the upper digestive tract and so reducing the chance of contamination and for ease of processing gizzards. The bird will lose weight during feed withdrawal, and this will average about 10 g/hr depending on age and liveweight. A significant portion of this loss will be excreta evacuation by the birds. The loss in eviscerated carcass weight is closer to 2 g/hr, with equal losses to breast and leg/thigh meat. Feed withdrawal does not seem to have major effects on blood or liver glucose or glycogen levels, and this may be the reason for there being fewer post-mortem changes such as PSE as occurs with pigs and sometimes turkeys.

In addition to the concern about gut fill at processing, there is now interest in the pathogen load of the digestive tract. The ceca have a very high bacterial load and some of these will be

pathogens of concern regarding food safety. In a recent study, broilers were held on the litter or in crates for 24 hr without feed and surprisingly there was little change in pH of the cecal contents or the bacterial populations. In fact, there were few lactic acid producing bacteria, which is a situation that allows pathogens to flourish.

Excessively long periods of feed withdrawal seem to actually increase the pathogen load in the upper digestive tract. With 12 hr+ of feed withdrawal, there are often high counts of *Campylobacter* in the upper digestive tract, and again this is associated with a reduction in the presence of lactic acid producing organisms. With prolonged feed withdrawal, broilers are more likely to eat litter and this seems to be the source of the pathogens. Because problems are often correlated with reduced populations of *Lactobacilli* type organisms, there is interest in offering birds lactic acid in the water during feed withdrawal. Water with 0.5% lactic acid has been shown to reduce the incidence of *Salmonella* and *Campylobacter* in the upper digestive tract by at least 80%.

A more serious concern arises if birds are accidentally without feed for 12 hr+ in the 2 - 3 d prior to feed withdrawal. Broilers again are seen to eat litter, drink excessive amounts of water and so produce very wet manure. Both sexes have been observed to lose up to 100 g body weight after 18 hr of no feed being available. Coupled with a potential growth of 70 – 80 g in this period, means that birds are at least 170 g behind expected standard weight. There is some compensation when feed is reintroduced, with birds eating up to 300 g in the first 24 hr following refeeding. Depending upon time of feed outage relative to eventual withdrawal, means the bird can have excessive quantities of digesta throughout the intestine.

The other aspect of late cycle broiler nutrition is potential for reducing nutrient levels, and particularly the inclusion of trace minerals, vitamins and various feed additives. Broilers seem most responsive to total withdrawal of vitamins, than to removal of trace minerals (Table 5.27).

Table 5.27 Broiler growth and F:G from 42 – 49 d in response to vitamin and trace mineral supplementation

Vitamins	*Minerals*	*Growth*	
		(g)	*F:G*
+	+	*564*	*2.41*
+	-	*562*	*2.40*
-	+	*537*	*2.58*
-	-	*481*	*2.85*

Adapted from Maiarka et al. 2002

Feed efficiency and growth are both compromised by total withdrawal of vitamins from the feed, and this effect is accentuated when trace minerals are also removed. There is also concern with higher mortality when vitamins and minerals are withdrawn under heat stress conditions (Table 5.28).

Table 5.28 Removal of vitamins and trace minerals from heat-stressed (24-35˚C) broilers

Vitamins	*Minerals*	*35-49 d wt gain (g)*	*F:G*	*Mortality (%)*
+	+	*1280[a]*	*2.66[a]*	*9.6*
-	-	*1240[b]*	*2.86[b]*	*13.2*

Adapted from Teeter (1994)

There are inconsistent reports on the effects of removing anticoccidials and growth promoters during the last 5 – 10 d. This situation probably relates to health status of individual flocks, and level of biosecurity etc. Since many ionophore anticoccidials seem to influence proliferation of necrotic enteritis, then if growth promoters are not used in a feeding program, removal of ionophores for an extended period can compromise bird health and performance.

5.3 Assessing growth and efficiency

a) Broiler growth

With yearly increases in genetic potential, standards for growth rate become quickly dated. Over the past 20 years, there has been at least an annual increase of 25 g in body weight at 42 d of age, and in certain periods we have seen gains of 30 – 50 g each year. This growth rate is fueled by feed intake. With increasing growth rate, there has been ever increasing efficiency of gain. It seems unlikely that the bird has increased its ability to digest protein, amino acids and energy from commonly used ingredients, and so, change in efficiency is simply a consequence of reduced maintenance need. While there has to be a biological limit to growth rate, it is likely that management concerns will be the issue that imposes a lower limit on market age. For example, there is now concern on the 'maturity' of the skeleton of female broilers destined for the 1.75 kg market, where market age could be 30 d or less within the next 5 – 7 years.

Factors influencing feed intake have the single largest effect on growth rate. Birds eat more in cooler environments and vice-versa, although this situation is confounded with humidity, acclimatization and stocking density. As a generalization, maintenance energy requirement increases by about 3% for each 1˚C decline in environmental temperature below 30˚C. If maintenance represents 60% of total energy needs, then feed intake is expected to change by about 2% for each 1˚C change in temperature. Under commercial conditions stocking density is going to be one of the major variables affecting growth and feed intake (Table 5.29).

With a higher stocking density, birds eat less feed, presumably due to greater competition at the fixed number of feeders. However this slightly reduced growth is often accepted since there is greater liveweight production from the broiler house.

It is generally assumed that broilers hatched from larger eggs will grow more quickly than those hatched from small eggs. As broiler breeders get older, they produce larger eggs and so broiler growth is often correlated with breeder age. In a recent study, we hatched broilers from breeders at 28, 38, 48 and 58 weeks of age, and grew them under standard conditions within the same broiler facility. Interestingly, the growth of female broilers was most highly correlated with breeder age (Table 5.30).

Table 5.29 Influence of stocking density on broiler performance

Density (birds/m²)	*49 d B.wt. (g)*	*Feed intake (g)*	*kg/m²*
10.5	*2337[b]*	*4973[b]*	*23.4[a]*
13.5	*2261[a]*	*4803[a]*	*28.9[b]*

Adapted from Puron et al. (1997)

Table 5.30 Broiler growth characteristics as affected by breeder age

	Breeder age (wks)			
	28	***38***	***48***	***58***
Male broiler:				
49 d live wt. (g)	*3186*	*3249*	*3221*	*3273*
0 – 49 d F:G	*1.88*	*1.80*	*1.86*	*1.96*
49 d carcass wt. (g)	*2498*	*2562*	*2610*	*-*
Deboned breast wt. (g)	*587*	*605*	*607*	*-*
Female broiler:				
49 d live wt. (g)	*2595*	*2633*	*2667*	*2712*
0 – 49 d F:G	*2.11*	*1.95*	*2.01*	*2.00*
49 d carcass wt. (g)	*1972*	*2028*	*2118*	*-*
Deboned breast wt. (g)	*462*	*468*	*492*	*-*

Table 5.31. Change in broiler live weight and carcass weight per 1 g increase in breeder egg weight

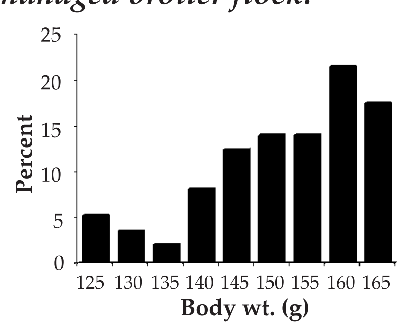
	Live weight	*Carcass weight*
Male broiler (49 d)	*+ 5 g/g egg wt.*	*+11 g/g egg wt.*
Female broiler (49 d)	*+ 8 g/g egg wt.*	*+14 g/g egg wt.*

There was a significant linear trend over time and from these data we can predict that both liveweight and carcass weight will be influenced by differences in egg weight that result as a consequence of increased breeder age (Table 5.31).

Larger eggs usually have larger yolks, and it is often suggested that yolk size is the factor influencing growth as shown in Tables 5.30 and 5.31. However, experimental removal of yolk material from an incubating egg has little effect on chick size at hatch. Removal of albumen does however cause reduction in chick size, and so perhaps it is the albumen content of large eggs that influences chick size and subsequent broiler growth. However, a confounding effect is that yolk size does influence the size of the residual yolk at hatch, and this may have some effect on early growth if chick placement is delayed.

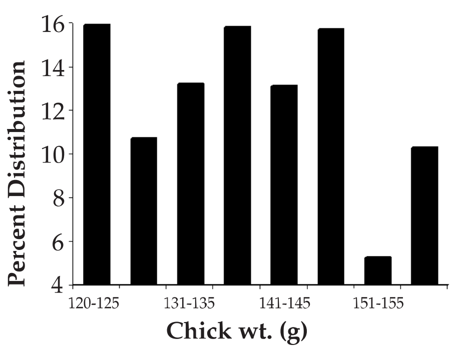
While growth rate is of prime economic importance, uniformity of growth is becoming of increasing concern. With mechanized feeding systems, small birds have difficulty reaching feed and water as they are raised to best suit the flock mean growth rate. The current lack of uniformity however, seems to start as early as the first week of age. Even in well-managed flocks, there is skewed distribution of that body weight, with a preponderance of smaller chicks (Figure 5.5).

Fig. 5.5 Distribution of chick weight in a well managed broiler flock.



When specific health problems occur, such as 'feed passage' or 'stunting-runting syndrome' then the weight distribution is heavily biased towards small chicks (Figure 5.6).

Fig. 5.6 Distribution of chick weight in a floor unit with obvious health problems.



In most flocks today there is a skewed distribution of 7 d body weight with the unevenness contributed by 12 – 15% of small chicks. This type of uneven distribution occurs even with hatches of eggs from individual breeder flocks. This early loss in uniformity influences subsequent flock characteristics.

Each 1 g change in 7 d body weight alters 18 d body weight by 3 g (i.e. a chick that is 30 g underweight at 7 d will be 90 g underweight at 18 d. By 49 d the correlation is 1 g @ 7 d 5 g @ 49 d.

It is well known that chick size is influenced by size of the hatching egg. A range of egg weights are set, but usually the extremely small and very large eggs are discarded. The current variance therefore occurs within the range of settable eggs. The effects seen in Figures 5.5 and 5.6 are made worse when broiler flocks are derived from a number of different age breeder flocks. However the problem is not fully resolved when eggs are graded prior to setting. There is a suggestion that yield of yolk and albumen is not highly correlated with egg size.

b) Feed efficiency

A measure of the efficiency of feed utilization is obviously of economic importance. Classical feed efficiency is calculated as feed intake ÷ body weight, while the converse measure of body weight ÷ feed intake is often used in Europe. Feed is used by the bird for two basic reasons, namely for growth and for maintenance. In young birds most feed is used for growth (80%) and little is used for maintenance (20%) and so efficiency is very good. Over time efficiency deteriorates because the broiler has an ever-increasing body mass to maintain. Table 5.32 shows expected changes in classical feed efficiency related to age of bird.

These data suggest that at around 1.75 kg body weight, feed conversion will increase by 0.01 units for each day of growth or that conversion will increase by 0.013 units for each 100 g increase in market weight. As the bird gets heavier, these units of change increase (Table 5.32).

Over the years we have seen a steady decline in classical feed conversion from around 2.2 in the early 1960's to 1.75 today under certain situations. This continually improving situation is due to improved genetic potential, and the fact that more feed is directed towards growth (and less for maintenance) as days to market decline.

Body weight is a consequence of feed intake, and so feed intake tends to be the main variable in assessing feed efficiency. Historically broilers were grown to 45 ± 3 days and fed diets with energy levels that were standardized across the industry. Under these conditions, the measure of classical feed efficiency is useful, and should relate directly to economics of production. Today, the

Table 5.32 Adjustments to feed efficiency based on body weight or age

Weight category	*Change in F:G per 100 g body wt.*	*Daily change in F:G*
1.75 kg	0.013	0.010
2.50 kg	0.015	0.014
3.50 kg	0.017	0.016

Table 5.33 Performance and economic considerations of feeding broilers diets of varying nutrient density

Mean diet energy[1] (kcal/kg)	*Relative feed cost*	*45 d male body wt (kg)*	*Feed:Gain*	*Relative feed cost/bird*
3000	100	2.7	2.10	100
3100	105	2.7	2.00	99
3200	114	2.7	1.90	102
3300	123	2.7	1.80	105

[1] *all other nutrients tied to energy*

industry grows birds over a vast range of ages/market weights, and there is now considerable variation in diet nutrient density. The fact that a classical feed efficiency of 1.9 is achieved with a certain flock, has to be qualified in terms of sex of bird, market age and diet nutrient density. The lowest numerical feed efficiency may therefore not be the most economical (Table 5.33).

As nutrient density increases, feed conversion predictably declines. However, body weight is unaffected. Since high nutrient dense diets cost more, the feed cost per bird will only be reduced if birds eat correspondingly less feed. In this example, the most economic situation arises with mean energy level at 3100 kcal/kg, even though classical feed efficiency is not optimized. So called 'broiler growth models' today should be able to identify the most profitable diet, given feed price, broiler prices, expected performance, etc. The diet is ultimately least-costed in the traditional way, but this prior selection is often referred to as 'maximum profit formulation". A more useful measure of feed utilization is efficiency of energy use. When efficiency is based on energy, the energy level of the diet is irrelevant, and so this major variable is resolved. Table 5.34 indicates expected energy efficiency in male and female broilers.

Table 5.34 Energy efficiency in broilers

	Energy intake Mcal/kg gain	
Market age (d)	*Male*	*Female*
35	-	5.35
42	5.39	5.83
49	5.84	6.28
56	6.30	6.80
63	6.63	-

Assesssment of efficiency can be taken further than the level of individual bird production to accommodate such factors as feed cost, carcass yield and stocking density. In the future we may even have to consider manure management in our assessment of production criteria (Table 5.35)

Table 5.35 Future considerations in assessment of efficiency of feed usage in broiler production

Criteria	*Measurement*	*Comments*
Energy efficiency	*Energy intake: weight gain*	*Energy is the most expensive nutrient, and so this value is important. To some extent, values are independent of feed intake.*
Feed cost	*Feed cost: weight gain*	*Takes into account the fact that the most expensive diet is not always the most profitable.*
Carcass yield	*Energy intake: carcass wt.* *Energy intake: breast meat* *Feed cost: carcass wt.* *Feed cost:breast meat*	*Takes into account the fact that birds of similar weight may not always yield the same amount of edible carcass.*
Bird placement	*Feed cost/kg bird/sq. meter floor space/yr* *Economic return/sq. meter floor space/yr*	*Optimizes the use of the building e.g.: higher nutrient dense diets give faster growth rate, therefore more crops per year.*
Environment	*Nitrogen excretion/bird* *Phosphorus excretion/bird*	*Future considerations for environmental stewardship.*

5.4 Nutrition and environmental temperature

a) Bird response

Most broiler farms will be subjected to heat stress conditions for at least part of the year. The terms heat stress or heat distress are used to describe the conditions that affect broilers in hot climates. Because birds must use evaporative cooling (panting) to lose heat at high temperatures, humidity of the air also becomes critical. Consequently, a combination of high temperature and humidity is much more stressful to birds than are situations of high temperature coupled with low humidity. Other environmental factors, such as air speed and air movement, also become important. It is also becoming clear that adaptation to heat stress can markedly influence broiler growth. For example, broilers can tolerate constant environmental temperatures of 38˚C (100˚F) and perform reasonably well. On the other hand, most broilers are stressed at 38˚C (100˚F) when fluctuating day/night temperatures exist. In the following discussion, it is assumed that fluctuating conditions occur, because these are more common and certainly more stressful to the bird.

A market weight broiler produces about 5 – 10 kcals energy each hour. This heat, which is generated by normal processes in the body, must be lost to the environment by convection, conduction and/or evaporation. The broiler will conduct heat from its body to whatever it touches, assuming that these objects (litter, etc) are at a lower temperature than is body temperature (41˚C). The broiler will also convect heat away from its body, through circulating air, again

assuming that the air temperature is less than body temperature. The balance of heat production and heat loss is such that body temperature is maintained at around 41˚C.

Interestingly, under thermoneutral conditions, body temperature has little influence on performance. However, as body temperature gets much above 41.5˚C for broilers under heat distress, then there is good correlation between rise in body temperature and decrease in performance. Much above 42˚C mortality is inevitable.

In order to dissipate more and more heat, evaporative cooling has to be increased. Water balance and evaporative water loss of the broiler under non-heat stress conditions changes over time. In the first week of life, about 35% of total water intake is excreted through evaporative losses. By seven weeks of age, this amount increases to 70%. This increased emphasis on evaporative water loss with age is one of the reasons why the older bird has more problems in balancing its heat load during heat stress, because evaporative systems are so heavily relied upon under normal conditions. The bird does not have sweat glands, and so at high temperatures, evaporative cooling is the only effective means of greatly increasing heat loss. As the bird pants under heat stress conditions, water vapour is lost in the exhaled air with each breath. Some heat is lost in raising the temperature of exhaled water vapour, from ambient (drinking water temperature) to that of body temperature. However, this heat loss is insignificant in relation to the heat loss needed to evaporate water. About 0.5 kcals of energy are lost for each gram of water evaporated during breathing. A market weight broiler producing 200 kcals heat energy per day needs almost 400 grams water loss by evaporation. This is an extreme case, because other heat dissipation mechanisms are also active and the bird also loses some water via the urine. However, this simple calculation does emphasize the need for increased water intake during excessive heat stress. Unfortunately, the situation is made worse by the fact that cooling mechanisms, such as panting, generate significant quantities of body heat. In fact, it has been calculated that panting introduces an extra 20 – 25% heat load on the bird.

The major heat load in the body arises from the digestion and metabolism of food. A simple way of avoiding heat stress, therefore, is to remove feed. Under less stressful conditions, we are interested in maintaining growth rate close to genetic potential, and this means feeding at close to normal physical intake. However, different nutrients produce different quantities of heat during metabolism. For example, the metabolism of fat is most efficient, and metabolism of protein is least efficient in this respect. Unfortunately, the metabolism of all nutrient is far from being 100% efficient, and so even for dietary fats, there will be some heat evolved during normal metabolism.

This means that diet formulation can be used to advantage in trying to minimize heat load. Unfortunately, the major heat load is going to be a consequence of feed intake *per se* (Table 5.36).

Table 5.36 Energy balance of a 2 kg broiler (kcal/bird)

	Feed/day			
	0 g	50 g	100 g	150 g
24˚C environment:				
Heat production	192	204	212	236
Sensible loss	160	168	180	192
Evaporative loss	44	40	44	48
Balance	-12	-4	-12	-4
35˚C environment:				
Heat production	196	220	240	248
Sensible loss	88	112	96	132
Evaporative loss	72	88	92	96
Balance	36	20	52	20

Adapted from Wiernusz and Teeter, (1993)

Table 5.37 Male broiler feed intake at 15-30˚C

	Male broiler (g feed/bird/day)			
Age (d)	15 ˚C	20 ˚C	25 ˚C	30 ˚C
14	78	72	65	59
21	120	110	100	90
28	168	154	140	126
35	204	187	170	153
42	240	220	200	180
49	264	242	220	194

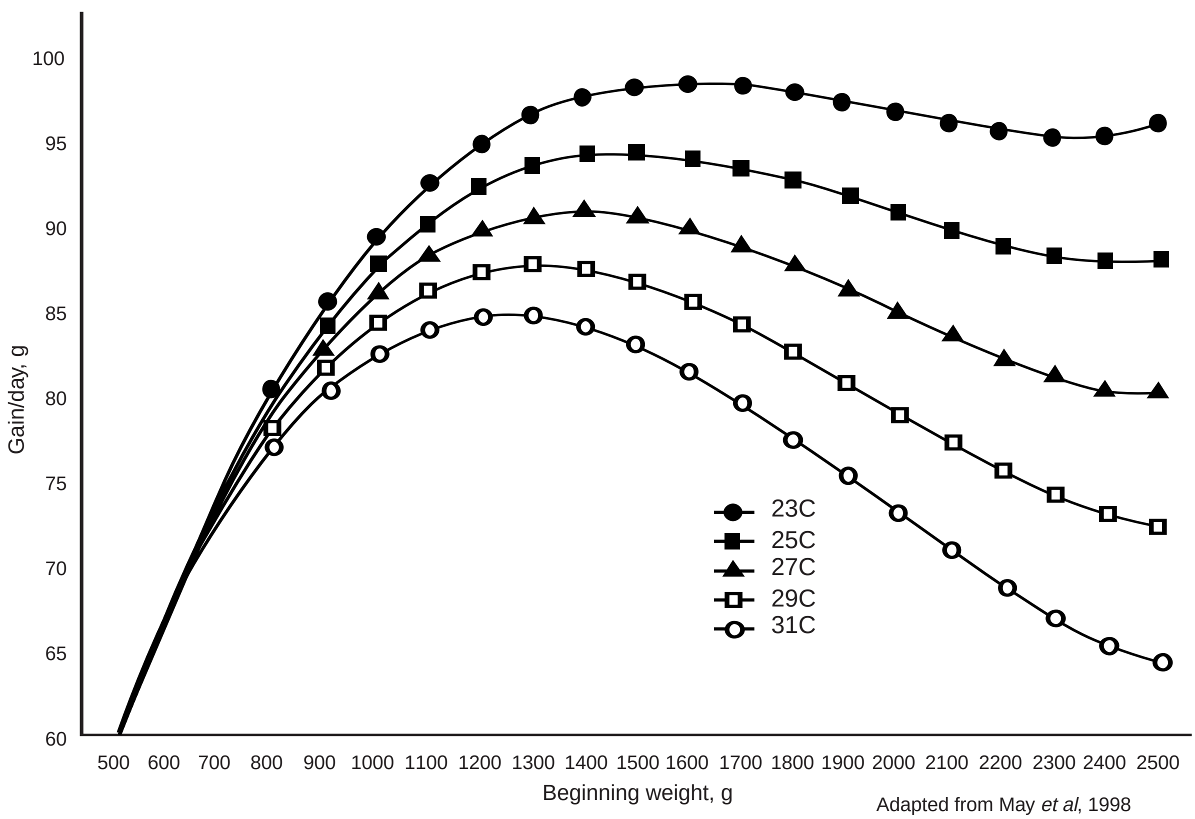
At 24˚C, the broiler is in near perfect balance, with heat production being similar to heat dissipation. At 35˚C, the broiler is in severe positive energy balance, where heat dissipation cannot match the heat load generated by feed metabolism. In this situation, the broiler has to quickly correct the balance, and the easiest solution is to reduce heat load by voluntary reduction in feed intake. Such changes in feed intake will occur very quickly, certainly within hours, because the birds must maintain the balance at close to zero. Table 5.37 shows the expected feed intake of male broilers housed at varying environmental temperatures.

Broilers will acclimate to warm conditions and can perform reasonably well at constant temperatures as high as 36˚C. However, if broilers are normally held at 25˚C a sudden change in temperature to 36˚C may prove fatal, and will certainly influence growth rate. There is some research to suggest that intentionally subjecting young broiler chicks to high temperatures enables them to better withstand subsequent heat stress conditions when they are older. Such acclimated birds seem to show less of an increase in their core body temperature when later (up to 4 – 6 weeks) exposed to high temperatures. Heat acclimatized birds do seem to drink more

water and eat more feed under heat stress conditions. Therefore, because acclimatized birds are prepared to eat more feed, this induces a greater heat load, so this can counterbalance the effect of prior acclimatization. For prior acclimatization to be useful therefore, it seems necessary to combine this with some degree of feed restriction if maximum benefits are to be achieved. It is likely that the confounding effect of 'increased' feed intake by acclimatized birds is responsible for variation in results of trials and field studies of early life heat stress acclimatization.

The general growth response of male broilers of 500-2500 g body weight to a range of environmental temperatures is eloquently shown by the data of May *et al*. (1998).

Fig. 5.7 Effect of environmental temperature on daily growth of male broilers.



Adapted from May *et al*, 1998

b) Potential nutritional intervention

Nutritional intervention to limit the effects of heat stress include change in levels of nutrients, change in ingredient composition, time of feeding and in extreme situations, removal of feed.

In terms of nutrients and ingredients, the level of crude protein should be minimized and the level of supplemental fat increased to practical maximums. It is usually not economical to use constraints for crude protein that increase overall diet cost by more than 5 – 8%. In general, economical reductions in crude protein level are in the order of 2 – 3% (e.g. 22 $\longrightarrow$ 20% CP). A major problem related to metabolism of proteins is the heat increment related to transamination (rearrangement), deamination (breakdown), and excretion of nitrogen as uric acid in the urine. It follows therefore, that amino acid balance within a diet is as important as the total level of crude protein. With 4% excess CP in a diet (due to using poorer quality ingredients, while trying to achieve the level of limiting amino acids), the bird's heat output is increased by 8 – 10%. Protein quality, therefore, becomes critical in these diets.

Because energy intake is often the limiting factor to growth during heat stress, it is tempting to recommend high-energy diets that contain high levels of supplemental fats. Unfortunately, the broiler is still eating to its energy requirement, so simply increasing the energy concentration of a diet does not ensure a major increase in energy intake. Broilers will tend to eat more energy with higher energy diets, so it can be useful to consider such a formulation change although in itself this change will not correct growth depression.

Acid:base (electrolyte) balance in the broiler is altered at high temperatures because of the associated effect of increased carbon dioxide loss due to panting. There has been considerable research in this area, investigating the potential of maintaining normal anion:cation balance during heat-stress. However, the general consensus at this time is that acid:base balance *per se* is not a major factor influencing either growth rate or survival of broilers in heat stress conditions. This is not to say that adding electrolytes to the feed or water is ineffective, rather, their mode of action may be other than by altering or maintaining acid:base balance.

It seems as though the benefit of adding electrolytes to the feed or water is simply to increase the bird's water intake which in turn fuels evaporative cooling. Various studies have been conducted in which broilers have been given mineral supplements in the water, producing a range of anion-cation balance. For example, both $(NH_4)_2SO_4$ and $NaHCO_3$ are effective water supplements used in trying to combat heat stress, yet their ion balances are very different. The beneficial effects of these supplements seem more closely correlated with their effects on water intake.

Adding a mineral salt, such as KCl increases water intake and evaporative heat loss of the bird. A common treatment and/or preventative measure during heat stress, is to add NaCl at 0.5% to the birds' drinking water. For broilers eating 100 g of feed containing 0.2% Na (0.5% salt) each day, means that birds consume 30% of their daily Na from feed and 70% of Na from treated water. The level of water supplementation should therefore, represent a significant increase in the birds' Na (or K) intake. Maintaining or stimulating water intake seems to be a key factor in maintaining growth rate of older broilers subjected to hot environments. In this regard, the use of drinker equipment is a factor (Table 5.38)

Birds were always heaviest when using the open trough drinkers, and nipple height also influenced growth. At 30˚C, the difference in growth for birds using open trough vs. nipples is greatly accentuated. The actual reason behind better growth with open trough drinkers is not fully resolved. It is likely that birds drink more water, but they also may immerse their wattles in open trough drinkers and this aids evaporative cooling. However, nipple drinkers are often preferred, since litter condition is easier to manage. Nipple height is also critical for optimum water intake. As a rule-of-thumb nipple height should be at 10 cm at day of age, and then increase by 5 cm per week.

In situations when broiler mortality is the main concern, the best recourse is to remove feed, so as to reduce heat load on the bird. The time of peak mortality due to heat stress is usually in late afternoon, which does not always coincide with the hottest time of the day. The late afternoon period does, however, coincide with the time of peak heat of digestion and metabolism for birds eating substantial quantities of feed in the early-mid morning period. Consequently, it is often recommended to withdraw feed prior to anticipated time of peak environmental temperature, to minimize the heat load of the bird.

A common management scenario is to remove feed at 10 a.m. and re-feed at 5 p.m. Such a system assumes having some supplemental lights so that they can eat at cooler times of the day. Table 5.39 summarizes recommendations for feed formulation and feeding management for heat stressed broilers.

Table 5.38 Broiler growth at 25˚C vs 30˚C using open trough or nipple drinkers (g/bird)

Water system	*25 ˚C*		*30 ˚C*	
	28 d	*49 d*	*28 d*	*49 d*
Open trough	*1424*[a]	*3275*[a]	*1349*[d]	*2632*[d]
Low nipple	*1411*[b]	*3199*[b]	*1336*[e]	*2395*[e]
Medium nipple	*1400*[b]	*3164*[b]	*1333*[e]	*2300*[f]
High nipple	*1385*[c]	*2995*[c]	*1303*[f]	*2104*[g]

Adapted from Lott et al. (2001)

Table 5.39 Strategies for reducing the impact of heat stress

Strategy	*Activity*
Feed formulation	*1. Reduce crude protein by 2 – 3%.* *2. Maintain levels of Meth + Cys, Lysine and Threonine.* *3. Increase diet energy by direct substitution of 2% fat for 2% of major cereal.* *4. Add 250 mg Vitamin C/kg diet.* *5. Use only highly digestible ingredients.* *6. Select appropriate anticoccidials.*
Feed management	*1. Withdraw feed 10 a.m. – 5 p.m.* *2. Ensure adequate feeder space and drinkers.* *3. Manage nipple height according to bird age.* *4. Add 0.5% salt to the drinking water.* *5. Keep drinking water as cool as possible.*
Bird management	*1. Increase air flow at bird level.* *2. Maintain litter quality.* *3. Use lower stocking density.* *4. Do not disturb birds at time of peak heat distress*

5.5. Nutrition and lighting programs

Lighting programs are now used routinely in growing broilers, and in some European countries it is mandatory to give broilers a period of darkness. An extended period of darkness each day seems to reduce the incidence of SDS and leg problems, and in winter months may help to control ascites in heavier males. The major advantage to these light programs is a period of rest and/or tempering of growth rate, which both seem to improve livability. There may also be some subtle effects of light that influence the bird's metabolism. In addition to influencing sex hormone output in mature birds, light also affects the pineal gland at the base of the brain, and this is responsible for production of another hormone, namely melatonin. Melatonin is produced during long periods of darkness, and is the hormone responsible for shutting down the reproductive system in wild birds during the fall. Broilers subjected to long periods of darkness will produce more melatonin, and this is thought to be involved in some way with the beneficial effects of such light programs. Adding synthetic melatonin to the diet of broilers does cause a calming effect, but does not seem to have any influence on mortality. The main feature of a lighting program for an immature bird such as the broiler is simply that during darkness, birds are more reluctant to eat, and so this controls growth rate.

If one visits 20 different broiler farms, it is possible to see 20 different lighting programs. However, all have the common feature of imposing a long period of darkness that lasts for at least 8 hours. Differences occur in the ages at which the light restriction is initiated and the pattern of returning to a longer daylength.

Broilers are reluctant to eat in the dark, and so the major 'activity' during darkness is simply sitting. However, some birds will attempt to eat and drink at this time and this disturbance can cause scratching and downgrading of the carcass. Such problems, which lead to infection, will be more prevalent with high stocking densities, and when longer (> 8 hr) periods of darkness are used after 22 – 25 days of age. The shorter the period of light the greater the reduction in feed intake, and so the greater the control over growth. If birds are kept on constant short days to 49 d (i.e. no compensatory step-up) then growth rate will be reduced. On average, for each 1 hour of darkness, broiler growth will be reduced by 20 g. Therfore, keeping birds on constant 12 hr vs. constant 24 hr from 1 – 49 d, will reduce growth by about 240 g. However, the reduced growth will be accompanied by reduced mortality. In practice, it is more common to step-up the hours of light after 2 – 3 weeks, and this allows for growth compensation.

There is little doubt that short-day lighting programs are most beneficial for male broilers. They are particularly successful for males grown to heavier weights and less useful (and perhaps detrimental) to lightweight females. Table 5.40 shows typical research results for 49 d male broilers.

While broilers will be smaller during the period of extended darkness, they are able to compensate by 49 d. Mortality is reduced, and especially the incidence of leg disorders. Although often not statistically significant, there is usually a slight reduction in breast meat yield for broilers on reduced daylength as shown in Table 5.40.

As previously mentioned, there are many different light programs, and selection depends on sex of bird, diet nutrient density, pellet quality, market weight and whether or not blackout or open-sided housing is used. In addition, the extended period of darkness may be less severe or shortened somewhat in the summer vs. winter, since hot weather also reduces growth rate, and the two combined can cause delay in grow-out. Table 5.41 summarizes the factors influencing choice of light program. Table 5.42 shows examples of lighting programs taking these factors (Table 5.41) into account.

Light intensity can also influence bird activity and feed intake. The higher the intensity, usually the greater the bird activity and so this can lead to more maintenance costs, and poorer feed efficiency. Higher body weights and better feed efficiency have been recorded at 5 vs. 150 lux. Light intensity after brooding should be at 2 – 5 lux, which is the minimal intensity for the stockperson to adequately inspect birds and equipment.

Table 5.40 Effect of step-down, step-up lighting for male broilers

Treatment	*49 d B. wt. (kg)*	*F:G*	*Mortality (%)*	*Leg problems (%)*	*Breast yield (%)*
23L:1D	*2.86*	*1.85*	*8.5*	*20.0*	*24.8*
Step-down:Step-up	*2.82*	*1.86*	*3.0*	*9.5*	*24.2*

Adapted from Renden et al. (1996)

Table 5.41 Factors influencing choice of light program

Parameter	Consideration for light:dark schedule
1. Strain of bird	Earlier fast growth means need for earlier introduction of reduced daylength.
2. Diet nutrient density	With higher nutrient density there is more benefit to a longer and more extended period of darkness.
3. Pellet quality	The better the pellet quality, the greater the need for light control.
4. Market weight	For older, heavier birds, delay step-up schedule.
5. Open sided vs. blackout housing	Open-sided housing dictates the maximum period of darkness. With blackout housing there is absolute control over duration and intensity of light period.
6. Season	Less severe programs in hot weather because growth-rate is already reduced.

Table 5.42 Examples of light programs for birds grown to 42 or 56 d in either summer or winter, in open or blackout houses (hours light/day)

Age (d)	Black out				Open-sided			
	Summer		Winter		Summer		Winter	
	42 d	56 d	42 d	56 d	42 d	56 d	42 d	56 d
0 – 5	23	23	23	23	23	23	23	23
5 – 8	14	12	12	10	Natural	Natural	Natural	Natural
8 - 12	14	12	12	10	Natural	Natural	Natural	Natural
12 – 16	14	12	14	12	14	Natural	Natural	Natural
16 – 20	16	14	14	12	16	14	14	Natural
20 – 24	16	14	16	14	16	14	14	14
24 – 28	18	16	16	14	18	16	16	14
28 – 32	18	16	18	16	18	16	16	16
32 – 36	18	16	18	16	18	16	16	16
36 – 40	18	18	18	16	18	18	18	16
40 – 44	18	18	18	18	18	18	18	16
44 – 48	-	18	-	18	-	18	18	18
48 – 52	-	18	-	18	-	18	-	18
52 - 56	-	18	-	18	-	18	-	18

There is little information available on the effect of color (wavelength) of light on broilers. It seems as though wavelengths above 550 nm (purple-orange-red colors) cause reduced growth rate. On the other hand, shorter wavelengths, at the blue-green end of the spectrum produce increased growth rate. These effects are quite subtle (5% maximum) yet it is conceivable that light color could be used to either slow down or speed up growth rate at specific times during grow-out. Currently bulbs that produce light at a specific wavelength e.g. red or green, are very expensive.

Intermittent lighting is another option for managing broilers, although unlike the step-down step-up programs described previously, this system is intended to stimulate growth rate. Short cycles of light and dark are repeated throughout the day, the most common being eight cycles of 1 hr light:2 hrs darkness. The idea behind the program is that birds will eat during the light period and then sit down during the 2 hr dark cycle and be ready to eat again when lights return. Obviously adequate feeder space is essential with the program and it is only viable with black-out housing (Table 5.43).

With intermittent lighting, it is assumed that energy efficiency will be improved, since birds are inactive for 66% of the day. In the study detailed in Table 5.43, there was greater overall heat production for birds on the 1L:2D program, and so increased growth was simply a factor of increased feed intake.

Table 5.43 Male broiler growth with intermittent vs. continuous lighting

	Body weight (g)			
Lighting	***21 d***	***42 d***	***56 d***	***0 – 56 d F:G***
Continuous	*717*	*2393*	*3459*	*2.07*
1 hr L: 2 hr D	*696*	*2616*	*3637*	*2.03*
	NS	*	**	*NS*

Adapted from Ohtani and Leeson (2000)

5.6 Nutrition and gut health

Bacterial and parasitic infections of the gastro-intestinal tract are an ever present threat to broilers grown on litter floors. The microbial status of the tract is kept in balance by use of anticoccidials in conjunction with so-called growth promoters. The mode of action of growth promoters has never really been fully explained, yet when they are excluded from the diet, bacterial overgrowth can occur. The role of gut health in broiler performance has suddenly become topical because of current or pending legislation concerning use of antibiotics in poultry diets. With the current pressure on antibiotic use in animal diets, it seems less likely that new products will be developed, and so one scenario is that at most, only currently registered products will be available.

We are greatly hampered in the study of gut health by not knowing, with any great precision, the normal microflora present in healthy birds. It has been suggested that, at best, conventional culture techniques are isolating 50% of the species of bacteria present in the gut. Newer techniques involving DNA fingerprinting of microbes may give us a better understanding of the complexity of the microflora, and in particular, how they change in response to various diet

treatments. On the other hand, we are aware of the major pathogens, and as a starting point in maintaining gut health, it is more promising in the short-term to concentrate on their control.

The chick hatches with a gut virtually devoid of microbes, and so early colonizers tend to predominate quite quickly. The enzyme system and absorptive capacity of the newly hatched chick is also quite immature. As previously described in section 5.2b, selection of ingredients eaten by the chick in the first few days of life will undoubtedly influence microbial growth and perhaps microbial species. Any undigested nutrients will be available to fuel microbial growth in the lower intestine and ceca – if these happen to include pathogens, then the chick will be disadvantaged. The 'normal' gut microflora develops quite quickly, and so microbial numbers and species present on the hatching tray, in the hatchery, during delivery, and the first few days at the farm will likely dictate early colonization. While 'dirty-shelled' eggs may hatch quite well, they do provide a major source of microbial colonization for the hatchling.

The Nurmi concept of manipulating gut microbes relies on early introduction of non-pathogenic microbes. Ideally, these microbes will help prevent subsequent pathogenic colonizations. Today, there is not an ideal culture for such a competitive exclusion product, which is again a factor of our not knowing the profile of a healthy microflora. In the past, undefined cultures have been used with reasonable success, but now regulatory agencies are insisting on dosing birds only with accurately defined cultures. It seems that if competitive exclusion (CE) is to be successful, cultures must be administered as soon as possible, and time of placement at the farm may be too late. However CE is undoubtedly going to be one of the management tools routinely used in broiler production.

Rapid early development of the intestinal epithelium is also another prerequisite for normal digestion. The villi and microvilli grow rapidly in the first few days, and any delay in this process is going to reduce nutrient uptake. Presence of pathogens, mycotoxins and animal and plant toxins will all delay microvilli development. Selection of highly digestible ingredients, devoid of natural toxins where possible, is therefore important for rapid early gut development. As the epithelium develops within the microvilli, where mucus is secreted and this acts as an important barrier against pathogenic colonization and also auto digestion from the bird's own digestive enzymes. Some bacteria are able to colonize because they are able to breakdown this protective mucus layer. *Heliobacter pylori,* the bacteria that causes gastric ulcers in humans, secretes urease enzyme that destroys the protective mucus coating, thereby making the stomach wall susceptible to degradation by hydrochloric acid and pepsin. It would be interesting to study the gut microflora of birds fed high urease soybean meal.

In addition to capturing digested nutrients, the epithelium of the gut also secretes large quantities of water that aid in digestion. For each gram of feed ingested, up to 2 ml of water may be infused into the gut lumen, and this will subsequently be resorbed in the lower intestine. If the epithelium is damaged by pathogens or toxins, then it can become a net secretor of water, and this contributes to diarrhea type conditions. Some strains of *E. coli* can also secrete toxins that disrupt water balance and contribute to diarrhea. Rancid fats also contribute to diarrhea by causing sub-lethal injury to the microvilli epithelium

Without the use of antibiotic growth promoters, the incidence of necrotic enteritis and coccidiosis are often the main production concerns. It now seems obvious that one of the major

modes of action of growth promoters is control over necrotic enteritis caused by *Clostridium perfringens*. The association between coccidiosis and necrotic enteritis may be as simple as coccidial oocysts damaging the gut epithelium and so allowing for greater adhesion of clostridial bacteria. There is no doubt that judicious use of ionophore anticoccidials or coccidial vaccines are important in the control of necrotic enteritis.

There has been a significant increase in the incidence of necrotic enteritis (NE) in Europe following removal of growth promoting antibiotics. Unfortunately, broiler diets in Europe are often based on wheat as the major cereal and it is well documented that clostridia multiply and colonize more quickly when the diet contains much more than 20% wheat. An interesting observation in Europe is that clostridia are now colonizing the upper digestive tract as well as the normal site of adhesion in the small intestine. Coupled with increased incidence of NE, so called 'dysbacteriosis' is now common in European broiler operations, and represents abnormal microbial overgrowth in the absence of antibiotic growth promoters. This latter condition does not seem to be related to diet composition or ingredient selection. Necrotic enteritis is also more common if the diet contains pectins contributed, for example, by ingredients such as rye. While rye is not a common component of broiler diets, such findings indicate that digesta viscosity, and associated maldigestion, are ideal for bacterial proliferation. There is a suggestion that clostridial growth is greatly reduced in diets containing wheat that is processed through a roller mill, rather than a conventional hammer mill. Table 5.44 summarizes suggestions for trying to minimize the incidence of necrotic enteritis in birds fed diets devoid of antibiotic growth promoters.

Table 5.44 Actions to reduce the incidence of necrotic enteritis in broilers

Action	*Effect*
1. *Minimize feed changes*	*Change in ingredient/nutrient composition is associated with change in gut microflora*
2. *Use highly digestible ingredients*	*Undigested nutrients fuel bacterial overgrowth*
3. *Minimize the use of wheat (< 20% ideally)*	*Increased digesta viscosity leads to greater clostridial activity. Enzyme addition important*
4. *Process wheat through a roller mill*	*Change in digesta viscosity?*
5. *Use only quality fats and oils*	*Rancid fats injure the microvilli*
6. *Ensure low level of urease/trypsin inhibitor in soybean meal*	*Urease can destroy protective mucus barrier*
7. *Use ingredients with minimal levels of mycotoxins, especially up to 28 d of age*	*Toxins can destroy epithelial cells in the microvilli*
8. *Use appropriate ionophore anticoccidials or coccidial vaccines*	*Coccidiosis predisposes clostridial growth*

Another approach to maintaining gut health is microbial reduction in feed and water. There is no doubt that high temperature pelleting (□ 80˚C) can inactivate pathogens such as salmonella. However, 'sterile' feed is an ideal medium for subsequent bacterial colonization (since there is no competition for growth) and so a practical problem is to prevent subsequent recontamination between the time feed leaves the mill and is delivered to the feed trough. Organic acids, such as propionic acid, can help prevent such recontamination, and where allowed by regulatory agencies, formaldehyde is especially effective against colonization by salmonella.

Drinking water is another potential route of bacterial infection. Many farms utilize some system of water sanitation, such as chlorine at 3 – 4 ppm. While such sanitizers hopefully ensure a clean water supply at the nipple, they have no effect on gut health. Of more recent interest is the use of organic acids, such as lactic acid, as both a sanitizer and to manipulate gut pH. Adjusting water pH from regular levels of 7.2 – 7.5, down to pH 5 with products such as lactic acid are claimed to reduce pathogen load in young broilers. In a recent study, we observed improved growth with using drinking water at pH 5 vs. pH 7.5. Interestingly, at pH 4, produced by simply using more organic acid, we observed filamentous yeast growth in the water lines, and this impacted water intake by clogging nipple drinkers. Yeast are always present in poultry facilities and thrive in acid environments.

The other alternate dietary intervention for preventing bacterial overgrowth is use of mananoligosaccharides. Many pathogens such as *E. coli* attach to the gut epithelium by small appendages called fimbriae. These fimbriae actually attach by binding to mannose sugar receptors. If mannose sugars are included in the diet, they also attach to these binding sites and effectively block attachment by many strains of *E. coli* and *Salmonella*. Commercial products such as BioMos®, which is derived from the outer cell wall of *Saccharomyces* yeast, is often used as part of an alternative strategy to antibiotics. Such products seem most efficacious when used on a step-down program, such as 2 kg, 1 kg and 0.5 kg per tonne in starter, grower and finisher diets.

5.7 Metabolic disorders

There has been a steady decline in the incidence of classical metabolic disorders as a consequence of genetic selection for liveability. Metabolic disorders such as ascites, Sudden Death Syndrome (SDS) and leg disorders collectively still account for the majority of mortality and morbidity in healthy flocks, although the total incidence is now closer to 2 – 3 % vs. 4 – 5% just 10 years ago. In male broilers, SDS will usually be the major cause of mortality starting as early as 10 – 14 d of age. At high elevations, and/or in cool climates ascites can still be problematic and often necessitates tempering of growth rate as a control measure.

a) Ascites

Ascites is characterized by the accumulation of fluid in the abdomen, and hence the basis for the common name of 'water-belly'. Fluid in the abdomen is, in fact, plasma that has seeped from the liver, and this occurs as the end result of a cascade of events ultimately triggered by oxy-

gen inadequacy within the bird. For various reasons, the need to provide more oxygen to the tissues leads to increased heart stroke volume, and ultimately to hypertrophy of the right ventricle. Such heart hypertrophy, coupled with malfunction of the heart valve, leads to increased pressure in the venous supply to the heart and so pressure builds up in the liver, and there is often a characteristic fluid leakage.

Because of the relationship with oxygen demand, ascites is affected and/or precipitated by such factors as growth rate, altitude (hypoxia) and environmental temperature. Of these factors, hypoxia was the initial trigger some years ago, since the condition was first seen as a major problem in birds held at high altitude, where mortality in male broilers of 20 – 30% was not uncommon. Today, ascites is seen in fast growing lines of male broilers fed high nutrient dense diets at most altitudes and where the environment is cool/cold at least for part of each day. Mortality seen with ascites is dictated by the number of 'stressors' involved and hence the efficacy of the cardio-pulmonary system to oxygenate tissues.

Although growth rate *per se* is the major factor contributing to oxygen demand, the composition of growth is also influential, because oxygen need varies for metabolism of fats vs. proteins. Oxygen need for nitrogen and protein metabolism is high in relation to that for fat, although it must be remembered that the chicken carcass actually contains little protein or nitrogen. The carcass does contain a great deal of muscle, but 80% of this is water. On the other hand, adipose tissue contains about 90% fat, and so its contribution to oxygen demand is proportionally quite high. Excess fatness in birds will therefore lead to significantly increased oxygen needs for metabolism. At high altitude, these effects are magnified due to low oxygen tension in the air. Interestingly, broilers grow more slowly at high altitude, and comparable slower growth (4 – 5%) at sea level would virtually eliminate the incidence of ascites. Regions of high altitude invariably have cool night time temperatures (< 15 ˚C) and no one has really quantitated the effects due to altitude *per se* vs. cool night temperatures.

Keeping birds 'warm' is perhaps the single most practical way of reducing the incidence of ascites. As environmental temperature changes, there is a change in the bird's oxygen requirement. If one considers the thermoneutral zone following the brooding to be 24 – 26˚C, then temperatures outside this range cause an increase in metabolic rate, and so increased need for oxygen. Low environmental temperatures are most problematic, since they are accompanied by an increase in feed intake with little reduction in growth rate. While there is an increased oxygen demand at high temperatures due to panting etc., this is usually accompanied by a reduced growth rate, and so overall there is reduced oxygen demand. Under commercial farm conditions, cold environmental conditions are probably the major contributing factor to ascites. For example, at 10 vs. 26˚C, the oxygen demand by the bird is almost doubled. This dramatic increase in oxygen need, coupled with the need to metabolize increased quantities of feed, invariably leads to ascites.

Manipulation of diet composition and/or feed allocation system can have a major effect on the incidence of ascites. In most instances, such changes to the feeding program influence ascites via their effect on growth rate. However, there is also a concern about the levels of nutrients that influence electrolyte and water balance, the most notable being sodium. Feeding high levels of salt to broilers (> 0.5%) does lead to increased fluid retention, although ascites invariably occurs with diets containing a vast range of

salt, sodium and chloride concentrations. Apart from obvious nutrient deficiencies, or excesses as in the situation with sodium, the major involvement of the feeding program as it affects ascites revolves around nutrient density and feed restriction. Ascites is more common when high energy diets are used, especially when these are pelleted. Dale and co-workers grew birds on high energy diets designed to promote rapid growth and likely to induce ascites. There was no correlation between 14 d body weight and propensity of ascites, although birds fed 3000 → 3100 kcal ME/kg rather than 2850 → 2950 kcal ME/kg had twice the incidence of ascites.

When diets of varying nutrient density are used, there is a clear relationship of energy level and incidence of ascites (Table 5.45).

Because feeding program, nutrient density and growth rate are all intimately involved in affecting the severity of ascites, then there is invariably discussion on the possible advantages of feed restriction. The goal of such programs is to reduce the incidence of ascites without adversely affecting economics of production. It is expected that nutrient restriction programs will reduce final weight-for-age to some degree, and obviously there is a balance between the degree of feed restriction and commercially acceptable growth characteristics. Using feed restriction or restricted access time to feed, ascites can be virtually eliminated in male broilers (Table 5.46).

Although low energy diets have little apparent effect on growth rate, there is often reduction in ascites. Using high energy diets with access at 8 h/d is perhaps the most practical way of controlling ascites in problem situations. As shown in Table 5.46, elimination of ascites is at the cost of a 200 g or 2 d delay in growth rate. A 2 – 3 d delay in market age sounds quite a reasonable trade-off for a major reduction in ascites. However, careful economic analysis must be carried out to determine the real cost of such decisions. A one day delay in market age can be accepted if mortality is reduced by at least 2.5%.

Another factor to consider in diet formulation is the balance and the quality of the protein. Excess nitrogen must be removed from the body, and this is an oxygen demanding process. There is a potential to reduce the oxygen demand through minimizing crude protein supply while maintaining essential amino acid levels in a

Table 5.45 Effect of diet nutrient density and composition on incidence of ascites at 49 d

Diet ME (kcal/kg)	*Crude protein (%)*	*Added Fat (%)*	*Ascites mort. (%)*
2950	23	0	8.8
2950	23	4	8.7
3100	24	4	15.8
2950	21	0	9.0
2950	21	4	8.5
3100	22	4	12.0

Adapted from Dale and Villacres (1986)

Table 5.46 Incidence of ascites in male broilers fed restricted quantities of feed or limited access time to feed

Diet treatment	Weight gain	Mortality (%)	
	(g)	Total	Ascites
High energy (3000 ⟶ 3300)	2616[a]	12.8	3.8
Low energy (2900 ⟶ 3100)	2607[a]	11.3	1.4
High energy (8 h/d)	2422[b]	8.7	0.6
High energy (90% ad lib)	2452[b]	9.0	0.2

Adapted from Camacho-Fernandez et al. (2002)

diet. If we consider two diets providing the same level of available amino acids, but with 20 vs. 24% crude protein, then there will be a need for birds to deaminate an extra 4% CP in the high-protein diet. If birds consume 130 g feed/d, this means an extra 5 g/d of protein for catabolism. Such protein catabolism will likely result in uric acid and fat synthesis, and these are calculated to need 2 and 1 litres of oxygen per day respectively. Therefore, catabolism of an extra 5 g crude protein each day means a 3 litre increase in oxygen demand, which represents about an 8% increase relative to the bird's total requirements. There is an obvious incentive to minimize crude protein *per se,* because its catabolism merely imposes another stress on the oxygen demand of the bird. There has been recent interest in the metabolism of two specific amino acids with potential to influence incidence of ascites. Arginine is a precursor of nitric oxide, which acts as a potent vasodilator. Feeding more arginine should therefore lessen the effects of increased pressure within the cardiovascular system. Feeding an extra 10 kg arginine/tonne does, in fact, cause a dramatic reduction in pulmonary arterial pressure. Unfortunately synthetic arginine is prohibitively expensive and no natural ingredients are sufficiently enriched to supply such high levels in the diet. Groundnut and cottonseed meal are perhaps the richest sources of arginine, at around 4%. Taurine is an amino acid rarely considered in poultry nutrition. It is required by cats where deficiency causes heart defects somewhat similar to those seen with ascites. However, adding taurine to broiler diets has no effect on growth rate or cardio-pulmoary physiology, and with meat meal in the diet 'deficiency' is unlikely to occur.

If ascites mortality is sufficiently high, the following diet changes may be considered:

- Low energy feeds throughout the entire life cycle e.g.:

  Starter (2850 kcal ME/kg)
  Grower (2950 kcal ME/kg)
  Finisher (3100 kcal ME/kg)

- Use mash rather than pelleted feeds.
  Do not use too fine a mash diet, since this encourages feed wastage and causes dustiness at broiler level.

- Consider skip-a-day feeding from 7 – 20 d of age. Longer periods of restricted feeding may be necessary where ascites levels are very high. Water management becomes more critical with this system.

- Consider limit-time feeding, such that birds have access to feed for 8 – 10 hours each day. Extra care is needed in water management so as to prevent wet litter.

- Use no more than 21% crude protein in starter diets, 19% in grower and 17% in finisher/withdrawal.

b) Sudden Death Syndrome

Sudden Death Syndrome (SDS) has been recognized for over 35 years. Also referred to as Acute Death Syndrome or 'flip-over', SDS is most common in males and especially when growth rate is maximized. Mortality may start as early as 10 – 14 d, but most often peaks at around 3 – 4 weeks of age, with affected birds invariably being found dead on their back. Mortality may reach as high as 1 – 1.5% in mixed sex flocks, and in male flocks the condition is often the major single cause of mortality, with death rates as high as 2% being quite common. The economic loss is therefore substantial. Confirmation of SDS by necropsy is difficult as no specific lesions are present. Birds are generally well-fleshed with partially filled crop and gizzard. There seems little doubt that any nutritional or management factors that influence growth rate will have a corresponding effect on SDS. Sudden Death Syndrome can virtually be eliminated with diets of low nutrient density although these may not always be economical in terms of general bird performance. Research data suggests that diets based on pure glucose as an energy source result in much higher incidence of SDS compared to birds fed starch or fat-based diets. It seems likely that some anomaly in electrolyte balance is involved in SDS and that there is a genetic predisposition to this in terms of heart arrhythmia. In part, this is due to the fact that metabolic changes occur rapidly after death, and hence blood profiles taken from SDS birds will likely vary depending upon sampling time following mortality. SDS can be reduced or eliminated by nutritional or management practices that reduce growth rate. Obviously, such decisions will have to be based on local economic considerations. At this time, there is no indication of a single causative factor, and diet manipulation other than that related to reduced growth rate, is usually ineffective.

c) Skeletal disorders

Most broiler flocks will have a proportion of birds with atypical gait, although growth rate may be unaffected. There is now greater incidence of birds with twisted toes, yet again this is in birds that achieve standard weight-for-age. Most leg problems likely have a genetic basis, although severity of problems can be influenced by nutritional programs. The most common skeletal abnormalities seen in broilers are tibial dyschondroplasia (TD) and rickets. The fact that leg problems are more prevalent in broilers (and turkeys) than in egg-type birds, has led to the speculation of growth rate and/or body weight as causative factors. On this basis, one is faced with numerous reports of general nutritional factors influencing leg problems. For example, it has been suggested that energy restriction in the first few weeks halves the number of leg problems in broilers, while reduced protein intake results in fewer leg abnormalities. Similarly, restricting access to feeder space also seems to result in fewer leg defects. However, most recent evidence suggests that body weight *per se* is not a major predisposing factor to leg problems. From experiments involving harnessing weights to the backs of broiler chickens and poults it is concluded that severity of leg abnormality is independent of body weight and that regular skeletal development is adequate to support loads far greater than normal body

weight. There seems to be some disparity between the effects on skeletal development of (1) limiting the incidence by reducing the plane of nutrition and (2) failing to aggravate the problem by artificially increasing body weight. This apparent dichotomy suggests that it is the rate of growth rather than body weight *per se* that is a predisposing factor.

In addition to the confounding effect of genetics on skeletal development, there is also some effect of steroid hormones. Castrated turkeys have a higher incidence of leg abnormalities than do intact toms or those treated with testosterone. It is suggested that androgens act to fuse the epiphyses and shafts of long bones. There may well be major sex differences in the hormonal control of skeletal development related to the balance of androgens:estrogens. However, the effect of androgens:estrogens *per se* on skeletal development in the relatively juvenile broiler of today is perhaps questionable due to the fact that little sex differentiation in tibiotarsal length is seen until after 5 weeks of age.

It is often suggested that use of low protein diets reduces the incidence of leg disorders although this is likely a consequence of reduced growth rate. Diets high in protein can interfere with folic acid metabolism and in so doing, increase the incidence of leg problems. However, in recent studies involving folic acid deficient diets, we were unable to show an effect with 22 vs. 30% crude protein diets. In studying factors influencing skeletal development in broiler breeders and Leghorns, we have shown that while early skeletal development was little influenced by mineral and vitamin fortification, shank and keel lengths could be increased by feeding diets of higher protein content (22 vs. 16% CP). It is also conceivable that the ratio of amino acids:non-protein nitrogen may be of importance in the development of bone organic matrix. Evidence for this concept comes from experiments involving synthetic amino acids and purified diets. The bird's nitrogen requirement for optimum organic matrix development is often greater than the apparent requirement for growth. The wry neck condition sometimes seen in broiler breeders, and especially males, may also be related to disrupted amino acid metabolism. While not directly a skeletal abnormality, the condition seems to be related to the metabolism of tryptophan or niacin. During incubation, wry neck arises in the embryo because of greater muscle pull on one side of the neck, which together with pressure from the amnion, causes the 'apparent' skeletal deformity.

Certain feed ingredients have been associated with leg disorders. Much of the early work in this area centered on brewer's yeast and its ability to reduce leg disorders. With current interest in probiotics and other yeast-based additives, this idea may receive renewed attention. There are isolated reports of certain samples of soybean meal contributing to TD in broilers although this may simply be a factor of acid:base balance of the diet.

It is realized that feedstuffs contaminated with certain mycotoxins can induce or aggravate skeletal problems. Grains contaminated with *Fusarium roseum* have been shown to cause TD. Aflatoxin and ochratoxin both decrease bone strength, and this may be related to vitamin D_3 metabolism. Under such field conditions birds sometimes respond to water soluble D_3 administered via the drinking water, regardless of the level and source of D_3 in the diet. Attempts at reducing leg problems by minimizing microbial contamination of the litter have met with a varying degree of success. Adding sorbic acid to the diet, or treating litter with potassium sorbate improves leg condition only in isolated trials. A number of fungicides used in grain treatment can also themselves lead to leg problems. The presence of tetramethylthiuram significantly

increases the incidence of TD, while tetramethylthiuram disulphide causes the 'classical' condition of irregular penetration of blood vessels into the cartilage, which is a precursor to TD.

High chloride levels induce TD, although since there are no major shifts in plasma ions with TD, it is concluded that the problem is not simply related to defective calcification. The occurrence of crooked legs seems to be greater when chicks are fed diets with a narrow range of cations:anions and the incidence of TD and bowed legs appears to increase with increase in anion content of the diet. There may be a relationship between ion balance and vitamin D_3 metabolism. Increasing the chloride content of the diet from 10 to 40 mEq/100 g was reported to markedly enhance cartilage abnormalities when the cation (Na^+, K^+) content of the diet was low. Thus, with excess Cl^-, chicks become acidotic, although the condition can be corrected with dietary sodium and potassium carbonates, suggesting that if the diet is high in Cl^-, then it must be balanced with equimolar concentrations of $Na^+ + K^+$ in the form of readily metabolizable anions. Workers from France have indicated that liver homogenates from acidotic chicks lose 50% of their capacity to synthesize 1,25-cholecalciferol which is the active D_3 metabolite. This possibly infers a relationship between acid:base balance TD, and vitamin D_3 metabolism.

In certain situations, a deficiency of D_3 will mimic both Ca and P deficiency situations. While Ca deficient chicks are usually hypocalcemic and hyper-phosphatemic, D_3 deficiency invariable results in hypocalcemia and hypo-phosphatemia. In the D_3 deficient chick a greater relative P deficiency is caused by parathyroid hormone. In situations of D_3 repletion, the skeleton seems to respond much more slowly than does the intestine, since the immediate effect of re-feeding D_3 is better 'absorption' of the diet Ca. There is also evidence to suggest that D_3 is involved with collagen synthesis, where the maturation of collagen crosslinks seems D_3 dose related. While 1-25 $(OH)_2D_3$ is unlikely to be available to the feed industry, nutritionists now have the option of using , $25(OH)_2$ commonly referred to as Hy-D®. Since the synthesis of,25 $(OH)_2$ normally occurs in the liver, then products such as Hy-D® are going to be most beneficial when liver function is impaired for whatever reason.

While deficiencies of most vitamins have been associated with leg problems, pyridoxine has perhaps received the most attention. There is overwhelming evidence to suggest that low levels lead to skeletal abnormalities and/or that supplementation reduces the incidence. It has been hypothesized that pyridoxine may exert its beneficial effect via involvement with zinc homeostasis and in particular the formation of picolinic acid which is involved in intestinal zinc absorption. There is an apparent synergism between zinc, B_6 and tryptophan involved in the prevention of leg weakness. The situation with pyridoxine is further complicated through the effect of diet protein as previously described with folic acid. Common to many other diet situations, pyridoxine deficiency manifests itself through epiphyseal lesions consisting of uneven invasion of irregular blood vessels into the maturing growth plate. Presumably the higher level of diet protein increases the metabolic requirement for pyridoxine through such processes as transamination and/or deamination. While deficiencies of many vitamins can therefore, precipitate leg problems in broilers, there is also evidence to suggest that certain vitamin excesses may be detrimental. Very high levels of vitamin A in the diet increase the incidence of rickets, while impaired bone formation has been observed with excess dietary vitamin E. It must be pointed out however, that all these reported effects of vitamin excess

on bone metabolism relate to dietary levels grossly in excess (5 – 10 times) of normal feeding levels and hence would only be practically encountered under unusual circumstances.

As with vitamins, deficiencies, or excesses of a vast range of minerals, can also influence bone development. The effect of abnormal levels and/or ratios of calcium:phosphorus are well documented. Confusion sometimes exists with respect to diagnosis of calcium or phosphorus deficiencies, and accurate on-farm diagnosis of phosphorus deficiency vs. calcium excess is difficult, and immediate recommendations of diet change can be misleading prior to complete diet analysis. Identical lesions for the two conditions are seen suggesting that excess calcium forms insoluble $Ca_3(PO_4)_2$ in the intestine, thereby inducing phosphorus deficiency. Table 5.47 shows normal levels of minerals in bone ash, and so values which are much different to these are a cause for concern.

Table 5.47 Normal mineral content of bone ash

Calcium	*37%*
Phosphorus	*18%*
Magnesium	*0.6%*
Zinc	*200 – 250 ppm*
Copper	*20 ppm*
Manganese	*3 – 5 ppm*
Iron	*400 – 500 ppm*

The effect of manganese deficiency on the incidence of perosis is obviously well documented although some evidence suggests that interaction with iron may be a complicating factor. Administration of hydralazine, a manganese sequestering agent, causes leg defects very similar to those seen in classical manganese deficiency, and in fact, successful Mn treatment has been recorded in these situations. Hydralazine blocks collagen secretion and this can be restored by administration of Fe^{2+} or Fe^{2+} with Mn^{2+}, but not by Mn^{2+} alone. The agent seems to block the synthesis of hydroxylysine and within this mechanism there seems to be a step requiring Fe^{2+}. Copper metabolism has always been suspect in studies of leg problems, since there are certain similarities between the cartilage of copper deficient birds and those with TD. However, attempts to correct TD with supplements of Cu have invariable proved disappointing. Solubilization studies indicated that dystrophic cartilage (TD) is not deficient in cross-linked collagen, a situation often seen with classical copper deficiency.

Skeletal disorders are sometimes seen in the first few days after hatching and so it is possible that metabolic disorders are initiated during incubation. Skeletal mineralization starts at around the eighth day of incubation, and at this time the yolk serves as a source of calcium. Shell calcium is not utilized until about the 12th day of incubation, although during the course of embryonic development, the embryo will take up some 120 mg Ca from the shell. Culturing developing embryos in a medium deficient in calcium quickly results in gross skeletal abnormalities. There have been no reports linking breeder eggshell quality with bone formation in broiler offspring. Similarly, there have been relatively few reports of the effect of breeder nutrition and management on skeletal development of the embryo. There seems little doubt that more common leg problems, such as tibial dyschondroplasia (TD) are inherited to some degree and hence pedigree has a potentially confounding effect on studies of leg abnormalities. TD is related to a major sex linked gene, the recessive of which is associated with a higher incidence of TD. This situation suggests a large maternal component, and therefore, female lines would greatly influence the expression.

d) Spiking mortality

Spiking mortality affects young broiler chicks between the ages of 7 and 21 days, and is characterized by severe hypoglycemia. All affected birds exhibit extremely low blood glucose levels, which account for many of the observed signs of spiking mortality, including huddling and trembling, blindness, loud chirping, litter eating, ataxia and rickets. Mortality rates of around 1% are observed daily for three to five days. Chicks that survive, experience long-term stunting and growth reduction. There are now field observations of an increasing occurrence of spiking mortality in broilers fed 'all vegetable diets'. Among many suspected etiological agents of spiking mortality are viral infections, mycotoxins and feed anti-nutrients together with poor management practices, although mycotoxins and anti-nutrients have been dismissed as primary causative agents. The short time frame and low mortality rate experienced with spiking mortality might well be the result of a hormonal or metabolic disorder affecting young chicks during the period of rapid growth.

Field reports suggest that diets containing 'all-vegetable' feed ingredients produce a much higher incidence of spiking mortality. The linoleic acid concentration of these diets in particular has been directly related to the severity of the syndrome when it occurs. Calf-milk replacer in the drinking water is suggested for treatment. This product is high in casein which itself is a rich source of the amino acid serine. Blood glucose levels in birds are influenced by glucagon more so than by insulin, and serine is a precursor of glucagon synthesis. It is possible that 'all-vegetable' diets are 'deficient' in serine, and that this predisposes the bird to hypoglycemia. In a recent study, we observed reduced blood glucose in broilers fed vegetable diets, and that this could be corrected with milk powder, casein or serine (Table 5.48).

Table 5.48 Blood glucose level in 18 d broilers fed various supplements to all vegetable diets

Diet	*Glucose (mg/dl)*
Corn-soy-meat	*270[ab]*
All vegetable	*243[b]*
All vegetable + serine	*275[a]*
All vegetable + casein	*273[a]*
All vegetable + milk powder	*275[a]*

Adapted from A. Leeson et al.(2002 unpublished observations)

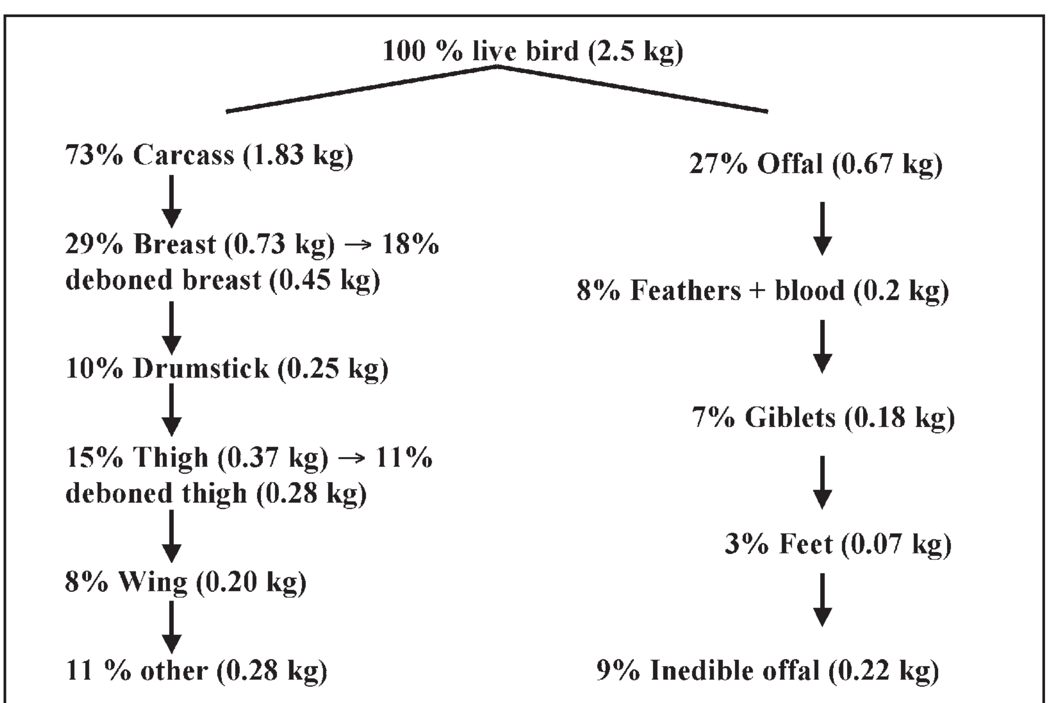
5.8 Carcass composition

During processing, cut-up and deboning, knowledge of expected yield is important in efficient scheduling of production. Carcass composition is affected by live bird weight, sex of bird and to some extent the nutrient content of the diets used and the feeding program. Modern strains of broiler have been developed for increased breast meat yield, and so obviously, this component has increased as a proportion of the carcass. At comparable weights, male and female birds have similar yields of carcass portions, and often the female will yield the most breast meat. However, since the female broiler tends to deposit more fat beyond about 2 kg liveweight, the yield of edible meat may be less than for the male if both are fed the same diet.

Energy and crude protein are the nutrients that have the greatest influence on carcass composition. Diets high in energy produce a fatter carcass while high protein diets result in a leaner bird. The situation is a little more complex than this, since it is actually the balance of protein to energy that is important. If the bird consumes excess energy in relation to protein, a fatter bird develops, whereas a leaner bird can be produced by feeding larger quantities of protein in relation to energy. Unfortunately, simple changes such as these are not economical, since the required degree of leanness in the carcass often only results from uneconomically high levels of protein.

When discussing the effect of diet protein or energy level on carcass composition, it is very important to appreciate the units of measurement. Often there is discussion about the effects of diet on percentage changes in composition, and in some situations the percentage of a component in the carcass changes simply because there has been a corresponding change in the level of another component. In fact, the grams of protein or meat on a carcass are little influenced by nutrition. Assuming there is no amino acid deficiency, then actual protein (meat) yield is dictated by genetics. Feeding more protein or more lysine for example than is required for optimum growth is going to have very minimal effect on protein deposition. So-called 'leaner' carcasses are therefore a consequence of there being less fat deposited. The fat content of a carcass is greatly influenced by nutrition. The more energy consumed by the bird, the greater the potential for fat deposition. Over the normal range of diet energy and protein levels used in industry, proportions of fat and protein can vary by about 3 – 4% due to nutrient intake. A 3% increase in carcass fat will be associated with 3% decrease in carcass protein, and vice-versa. Figure 5.8 details the component yield expected from a 2.5 kg live weight broiler.

Figure 5.8 Carcass components



The proportional yields are essentially a factor of body weight, and so there will be slight changes in major components for lighter or heavier birds (Tables 5.49, 5.50). The chemical composition of the carcass will also change over time; with increase in the proportion of fat and decrease in proportion of protein over time (Figure 5.9).

Figure 5.9 Chemical composition of the eviscerated carcass of male broilers

Table 5.49 Carcass weight and portions from male broilers (% carcass weight)

Live wt. (g)	*Carcass wt. (g)*	*Abdominal fat pad*	*Wings*	*Drums*	*Thighs*	*Bone-in breast*	*De-boned breast*
1224	*818*	*2.5*	*10.2*	*14.8*	*17.6*	*29.4*	*18.5*
1754	*1237*	*2.6*	*10.4*	*13.3*	*17.0*	*30.1*	*19.8*
2223	*1596*	*3.0*	*9.7*	*13.1*	*16.5*	*31.2*	*20.1*
2666	*1982*	*3.3*	*9.6*	*13.6*	*16.3*	*31.4*	*20.5*
3274	*2500*	*3.5*	*9.4*	*13.5*	*16.0*	*32.5*	*21.6*
3674	*2731*	*4.2*	*9.3*	*16.1*	*16.0*	*36.0*	*23.6*

Table 5.50 Carcass weight and portions from female broilers (% carcass weight)

Live wt. (g)	*Carcass wt. (g)*	*Abdominal fat pad*	*Wings*	*Drums*	*Thighs*	*Bone-in breast*	*De-boned breast*
1088	*720*	*2.8*	*10.8*	*14.4*	*17.5*	*29.5*	*20.4*
1582	*1160*	*3.2*	*10.5*	*13.8*	*16.6*	*29.7*	*19.5*
1910	*1376*	*3.4*	*10.2*	*13.6*	*16.5*	*31.5*	*21.5*
2382	*1753*	*4.3*	*9.8*	*13.2*	*16.4*	*32.5*	*21.7*
2730	*1996*	*4.3*	*9.6*	*13.0*	*16.4*	*34.2*	*22.6*

Table 5.51 Effect of feeding tallow, sunflower oil and flax oil from 28 – 48 d on fatty acid content of female broilers (% of total fat)

Body fat	*10% Tallow*	*10% Sunflower oil*	*10% Flax oil*
C14:0	*2.48*	*0.28*	*0.31*
C16:0	*23.10*	*10.70*	*10.9*
C18:0	*8.28*	*4.12*	*4.52*
C18:1	*41.74*	*19.09*	*18.97*
C18:2	*13.60*	*61.90*	*17.8*
C18:3n3	*1.39*	*0.99*	*43.0*

Adapted from Crespo and Esteve-Garcia (2002)

There is increasing interest in the manipulation of carcass fat composition related to human nutrition. As with eggs, the fatty acid profile of the diet has a direct influence on the fatty acid content of the carcass (Table 5.51).

The level of supplemental fat used in this study was higher than for commercial application, yet there is an obvious correlation between saturation of dietary fat and that deposited in the body. In terms of producing niche products for health conscious consumers, accumulation of total omega 3 fatty acids, and that of component linolenic acid, EPA and DHA are of interest. These long chain omega-3 unsaturates are most economically included in the feed as flax and fish oils (Table 5.52).

Adding flax to the diet results in enrichment of linolenic acid, while fish oil results in accumulation of EPA and DHA that also contribute to the omega-3's. The accumulation of specific fatty acids in the carcass seems to be a factor of dietary oil level and also feeding time. In this study, the supplements were fed only for the last 7 or 14 d of growth. It is obviously not essential to feed products such as flax or fish oil for the entire grow-out period, since significant enhancement occurs from feeding just from 42 – 49 d. The data shown in Table 5.52 relate to the intact eviscerated carcass. It seems as though the individual fatty acids accumulate at different rates in different regions of the carcass, and so marketing strategy may have to be modified if portions or deboned meat are produced from these carcasses (Table 5.53).

Thigh meat yields more omega-3 fatty acids than does a comparable quantity of breast meat, which is a factor of the amount of intramuscular fat in these portions. However, the greatest effect on fatty acid profile of individual portions, is presence or not of skin (Table 5.53).

Unlike the situation with eggs, production of 'designer' broiler meats enriched in various fatty acids can be complicated by problems of off-flavor. With only 0.75% of fish oil in the diet, panelist are reported to be able to detect more 'off-flavors' and rank these meats accordingly. The marketing of omega-3 broiler meat will require some entrepreneurial skill in overcoming these challenges.

Table 5.52 Effect of feeding flaxseed or fish oil for the last 7 or last 14 d on carcass fat composition in 49 d male broilers

Flax (%)	Fish oil (%)	Time (d)	Fatty acid (% of fat)			
			Linolenic	EPA	DHA	Total omega-3
-	-		1.3	0	0	1.3
10		7	3.4	0	0.1	3.6
10		14	5.3	0.1	0.1	5.7
-	0.75	7	1.3	0.2	0.1	1.8
-	0.75	14	1.3	0.4	0.3	2.1
10	0.75	7	3.3	0.3	0.2	3.9
10	0.75	14	6.0	0.5	0.3	7.1
-	1.5	7	1.4	0.4	0.3	2.2
-	1.5	14	1.4	0.8	0.5	2.9
10	1.5	7	3.6	0.4	0.3	4.5
10	1.5	14	5.9	0.8	0.5	7.7

Adapted from Gonzalez and Leeson (2000)

Table 5.53 Total omega-3 content of breast and thigh meat in birds fed flax or fish oil (mg/100g cooked meat)

Flax %	Fish oil %	Time (d)	Meat & Skin		Meat	
			Breast	Thigh	Breast	Thigh
10	-	14	673	995	143	206
-	0.75	14	380	393	182	98
10	0.75	7	484	708	118	163
10	0.75	14	858	1309	188	312

Adapted from Gonzalez and Leeson (2002)

5.9 Skin integrity and feather abnormalities

a) Feather development

Feathers are continuously being shed and regenerated by the bird, and even during the juvenile growth of the broiler, it undergoes 2 – 3 molts. Feathers arise from feather follicles that are arranged in distinct tracts on the skin. The follicle number is determined by about 14 d of incubation. The fact that the body is not uniformly covered by follicles means that certain areas of the skin would naturally be featherless. These areas will only receive a protective covering as feathers in adjacent areas grow, and overlap to cover the entire body. The younger the bird, the greater the area of apparently featherless skin. As the feathers grow, they conform to the shape of the bird's body and may lock together. Abnormal feather growth is often noticed when feathers are not contoured close to the body, and birds appear 'rough' or with 'helicopter wing' etc. Table 5.54 shows the composition of feathers from market weight broilers.

Table 5.54 Composition of feathers from 45 d broilers

	%
Crude protein	*90*
Total amino acids	*60*
Methionine	*0.7*
Cystine	*5.5*
Arginine	*7.1*
Lysine	*2.4*
Threonine	*4.2*
Valine	*6.5*
Magnesium	*0.2*
Sodium	*0.8*
Iron	*0.06*
Copper	*12 ppm*
Zinc	*10 ppm*
Selenium	*0.7 ppm*

Figure 5.10 Feather yield of sexed broilers.

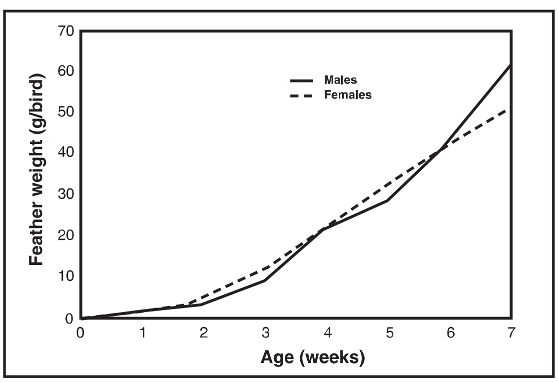
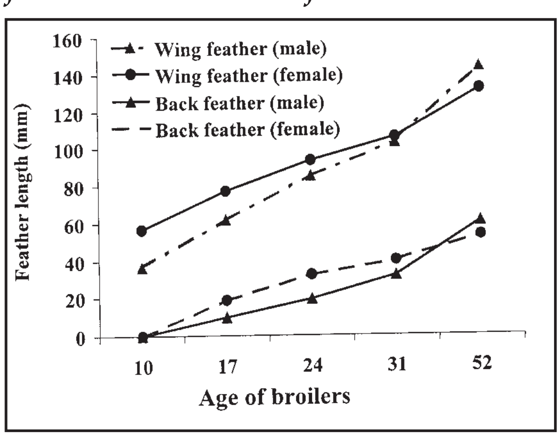


Figure 5.11 Growth of wing and back feathers in male and female broilers.



Adapted from McDougald and Keshavavz (1984)

Figure 5.10 shows feather yield of sexed broilers, while Figure 5.11 indicates standards for length of primaries and back feathers.

Feathers are composed mainly of keratin protein that is formed in the epidermis of the follicle. Virtually all growth occurs in the follicle, and so abnormalities seen 2 – 5 cm from the follicle will have occurred days or even weeks previously. The keratin structure is very rich in cystine, with each molecule containing around 8 half-cystine residues, and this is why methionine/TSAA levels are important for good feather structure. Marginal levels of methionine + cystine will cause abnormal feather growth and/or reduced feathering, although deficiencies of other amino acids will also cause feathering problems. With general amino acid inadequacy, the primary feathers have a characteristic spoon-like appearance that is caused by retention of an abnormally long sheath that covers the first 50% of the feather shaft. Deficiencies of many essential amino acids also cause abnormal curling of feathers away from the body. Interestingly, these same characteristics are seen with deficiencies of some of the B vitamins.

Birds fed T-2 toxin (4 ppm) develop only sparse feathering, and the feathers that do develop, tend to protrude from the bird at odd angles, leading to some areas of the skin begin exposed. With T-2 toxin, most feathers are affected, unlike the situation with nutrient deficiencies that most characteristically first affect the primary feathers.

Feather growth is also affected by thyroid function, and thyroid antagonists will delay normal feather growth. Poor feathering is sometimes seen at farms changing from corn to milo-based diets. While a number of diet situations may be involved in such a change, it is interesting to note that milo is very low in iodine content compared to other cereals.

Unfortunately, in most field cases of poor feathering, there is no apparent dietary deficiency as determined by routine analyses or consideration of formulation consistency/changes. Often problems are isolated to particular flocks within a site where all flocks receive the same feed. These factors support the concept of poor feathering being caused by infectious agents (likely in the feather follicle itself) or factor(s) causing general malabsorption of nutrients. Because feathers are very fast growing, especially in the first 7 – 14 d of age their development is very sensitive to general availability of circulating nutrients.

b) Skin tearing

About 5% of downgrades at processing are due to skin tears. Most tears occur post-mortem, and so are related to scald water temperature and pick time. High temperatures with shorter pick times cause less tears than lower scald temperature with prolonged pick time. However, regardless of processing conditions, a proportion of carcasses have torn skin. Skin strength is greater in males vs. females, and for both sexes, it increases with age. Most problems are therefore encountered with carcasses from younger female birds. There is a genetic component, because different strains show differences in skin tearing, and in one study it was shown that skin from slow feathering strains was less elastic than that from fast feathering birds.

Skin strength is highly correlated with its collagen content, and so skin with greater collagen content is less prone to tearing. Any nutritional factor that influences skin collagen content will therefore indirectly affect susceptibility to tearing. The amino acid proline is a component of hydroxyproline which itself is responsible for the stability and rigidity of collagen. Zinc, copper and vitamin C all play a role in collagen synthesis and so deficiencies of any one of these nutrients results in less skin collagen production. However, gross deficiencies of these nutrients also cause poor growth rate, a characteristic that is not usually seen in situations of excessive skin tearing. Unfortunately, there seems to be little benefit to increasing the dietary levels of these nutrients, or even increasing the level of proline in the diet.

A specific dietary situation involves the anticoccidial, halofuginone. When this product is fed at normal recommended levels, there is significant loss in skin thickness and skin strength, especially in female birds. In one study, using halofuginone (at 3 ppm of the diet) resulted in a 50% reduction in skin collagen content and 50% increase in the incidence of skin tears. Halofuginone seems to affect skin strength in female birds, more than it does with males, and because the female has an inherently weaker skin, this leads to the greater incidence of tearing. It has been shown that halofuginone interferes with the conversion of proline to hydroxyproline in the skin cells, and that this adverse effect cannot be corrected by adding more proline to the diet.

When skin tearing is a problem, assuming that processing conditions have been scrutinized, the only potential nutritional factors involved are halofuginone and level of zinc, copper and vitamin C. Skin tearing is more problematic in hot weather. This situation leads to recommendations of supplemental vitamin C, although birds under these conditions almost always carry more subcutaneous fat. Feeding higher levels of crude protein has also been shown to increase skin strength although the reason for this is not clear. More crude protein may provide more of the non-essential amino acid glycine which accounts for about 30% of the amino acids in collagen, or alternatively more protein *per se* may simply reduce carcass fatness.

c) Oily bird syndrome (OBS)

As its name implies, birds with OBS have skin that is oily or greasy to the touch. OBS is observed most frequently in older broilers and especially those fed high-energy diets in the warmer summer months. The problem also seems to relate to specific processing plants, where the occurrence is greater with the increased 'stress' applied during processing, and especially plucking. Interestingly, the condition is rarely seen in hand-plucked birds. The condition is also associated with increased water retention in the carcass, especially in regions of the carcass where skin 'elasticity' had been affected. These pockets of water are most often seen in female birds. The problem is most noticeable in pockets of the skin that separate in the back region. Because the skin seems more prone to tearing, these pockets rupture and the surrounding skin becomes noticeable oily.

A general finding in situations of OBS is a change in the skin ultrastructure, such that either the layers of skin separate to allow the pockets of oil and/or chilled water to accumulate, or the skin tears more easily. Apparently, fat saturation is not a factor in OBS, rather there is some change in the integrity of the various layers of the skin because the skin from affected carcasses is easily separated and removed from the underlying musculature. The five collagenous layers beneath the epidermis seem less compact than normal, and the deepest layers contain the most fat cells.

While there is no real change in total skin thickness with OBS, its breaking strength seems to be reduced. Although males usually have thinner skin than do females, it is usually stronger possibly due to there being less subcutaneous fat. Males also exhibit more insoluble skin collagen, and so this may be important in reducing problems of solubilization and water uptake as often occurs with OBS carcasses in chill water tanks.

The main collagen layer in birds with OBS is 30% weaker at normal body temperature and up to 50% weaker at temperatures used during processing. The problem may relate to impaired collagen crosslinking. In mammals, and in the formation of eggshell membranes, lysyl oxidase is thought to be the only enzyme involved in crosslink maturation of collagen and elastin, converting lysine and hydroxylysine into aldehydes. Lysyl oxidase is a copper metalloenzyme that requires pyridoxal phosphate as a co-factor, and copper deficiency is known to impair normal collagen crosslink structure. However, it does not seem as though copper deficiency is the simple solution to this problem.

OBS occurs only in broilers grown in warm climates, and experimentally the syndrome can only be duplicated by using warm growing conditions. At higher temperatures, birds carry more subcutaneous carcass fat, and so this may be the trigger mechanism. Because of the oily nature of the carcass, various diet ingredients and nutrient levels have come under investigation. Fat levels and sources in the diet have come under close scrutiny, although there does not seem to be a simple relationship. Higher levels of fat and/or energy in relation to the level of protein in the diet have caused more problems, although research results are inconsistent. Even though the bird's skin has an oily appearance, levels of unsaturated fatty acids do not correlate with OBS, and in fact, more problems are seen in birds fed tallow.

If OBS occurs, then the only immediate practical solution is to modify the processing conditions, and in particular, scald temperature and pick time. Because the exact cause of impaired collagen crosslinking has not been identified, then other changes to the diet and/or environment are of questionable value. While fat levels in the diet do not seem to be a factor, there is an indication of more problems occurring with saturated fats such as tallow. The diet should contain adequate levels of copper and not contain excessive levels of zinc or vitamin A.

5.10 Environmental nutrient management

Manure composition is now a factor in diet formulation. With the concentration of broiler production in many world locations, disposal of manure is now a constraint to production. The actual concern today is disposal of manure in a manner commensurate with environmental regulations. Most broiler farms are situated on a minimal land base and so, meeting environmental regulations now means transporting manure some distance from the farm. Where such transportation costs are prohibitive, then incineration is an option.

The current major concern with litter disposal, is its content of nitrogen and phosphorus. There is also awareness of content of other minerals such as zinc and copper and this is leading to re-evaluation of dietary needs for these trace minerals.

Broiler litter is relatively bulky and of low nutrient concentration compared to cage layer manure. The litter composition is dictated by the amount added to the broiler facility prior to brooding, and since there is little change in this quantity over time, this amount is predictable at time of clean-out. The most common litter materials used today are wood shavings, straw and rice hulls. All of these litter materials contain negligible quantities of nitrogen and phosphorus.

Table 5.55 outlines a series of calculations based on 10,000 broiler chickens eating 45,000 kg of feed.

Table 5.55 Calculations of manure production and composition per 10,000 broilers

Dry litter material		*2,000 kg*	
Feed intake 45,000 kg @ 90% DM @ 70% metabolizability			
∴	*12,000 kg dry matter excreted @ 60% DM*		
∴	*20,000 kg 'as is' excreta*		
∴	*22,000 kg 'as is' litter*		
∴	*Wood shavings/straw/rice hulls = 17% of DM of litter*		
∴	*Excreta = 83% of DM of litter*		
∴	*Wood shavings, etc. = 6% of 'as is' litter*		
∴	*Excreta = 94% of 'as is' litter*		
Litter = 4% N, 3% P_2O_5, 2% K_2O on 'as is' basis			
∴	*20,000 kg*	*@ 4% N*	*= 800 kg N*
		@ 3% P_2O_5	*= 600 kg P_2O_5*
		@ 2% K_2O	*= 400 kg K_2O*

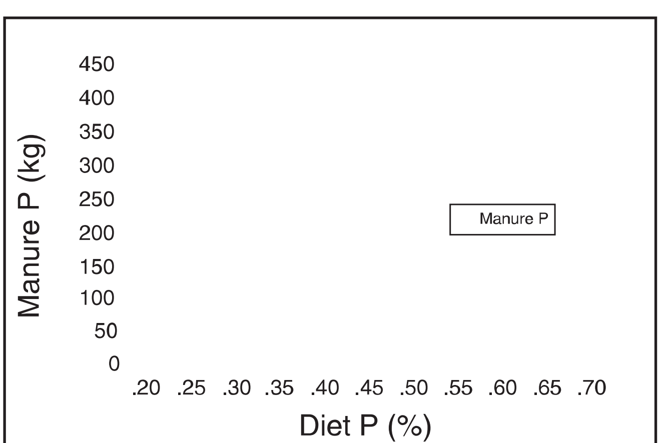
Feed intake and metabolizability of feed are going to be fairly consistent across the broiler industry for a given weight of bird. Consequently, the dry matter excretion of the flock will be quite predictable. The major variable will be the dry matter content of the final litter, and this will directly influence 'as is' concentration of nutrients. The moisture content of litter will be a factor of water intake, water holding capacity of the excreta, ventilation rate and humidity of outside air. In the example shown in Table 5.55, a value of 60% DM was used in the calculation. This means the litter has a water content of 40%. The above variables can combine to produce litter at 25-55% moisture in extreme conditions.

One of the main reasons for ventilation is to remove moisture from the building. If outside air is at high humidity, and close to saturation at a high temperature, there will be minimal moisture pick-up. If birds have loose and sticky manure, as occurs with some disease challenges or feed passage, the water holding capacity of excreta increases, and regardless of ventilation rate and humidity, the excreta releases little moisture, and again, this contributes to wetter litter. Diet formulation will also influence water intake, and so litter moisture content. High levels of protein, sodium and potassium are most often the reasons for increased water intake.

The nitrogen and phosphorus content of broiler feed has a direct effect on the content of these nutrients in manure. There is little variation in nitrogen content of broiler diets fed worldwide, and relatively little scope for further

reduction. Each 1% reduction in dietary crude protein influences litter nitrogen by only about 0.2%. Considering the size of the broiler industry today, a 0.2% reduction in manure nitrogen content is of global significance, yet at the farm level, this change is of little economic importance. As the protein content of diets is reduced, there is often loss in broiler performance, even though levels of methionine + cystine, lysine, tryptophan and even threonine are maintained by use of synthetic amino acids. Because protein and amino acids are relatively well digested by broilers, then there is minimal scope for reducing litter nitrogen content by diet formulation. There is more scope for reducing the phosphorus content of broiler litter through simple reduction in total phosphorus content of the diet. Depending on bird age only 30 – 60% of diet phosphorus is digested, and so the vast majority of ingested phosphorus is excreted in the manure. There is also more variance in diet phosphorus than for diet nitrogen, so again there is greater potential for standardization. The situation with phosphorus is also helped by the availability of phytase enzymes. Most phytase enzymes will liberate the equivalent of 0.1% available phosphorus and so diet formulation can be adjusted accordingly. There is a direct relationship between dietary available phosphorus and excreta phosphorus (Figure 5.12).

Figure 5.12 Manure Phosphorus output per 20,000 2.5 kg broilers



There are obviously lower limits to phosphorus content of diets, and the requirement for skeletal integrity is often higher than needs for general performance. The lower limits to diet phosphorus levels are therefore often dictated by carcass processing conditions. There is little doubt that diet phosphorus needs decline over time and that very heavy broilers have minimal requirements. For broilers much older than 60 d, it seems as though conventional ingredients, even of plant origin, can provide adequate phosphorus for 10 – 14 d.

When calculating manure phosphorus application rates, and the potential for run-off into streams etc, the situation is clouded by the concept of soluble vs. insoluble P in manure. The use of phytase does not seem to increase the proportion of soluble phosphorus in manure. Soluble phosphorus will presumably be available to plants, while truly insoluble phosphorus will be unavailable. Manure phosphorus that is soluble in citric acid is often considered as a measure of the phosphorus available to plants. If phosphorus is soluble there is concern that more will be lost as run-off into streams. However, the alternate argument is that truly insoluble phosphorus will not leach into soil, and so will always be subject to physical run-off depending on topography of the land. This issue seems to be a factor of soil chemistry, topography, season of manure application to land, and level and intensity of rainfall. With all of these variables, it is obvious that unanimous conclusions about the importance of phosphorus solubility in manure are not likely in the near term.

Of increasing concern is the level of trace minerals in broiler litter, again as it influences soil accumulation and water leaching. In some regions of the southern U.S.A. it is no longer possible to use broiler litter as fertilizer on land used to grow cotton since the accumulated zinc con-

tent of soil greatly reduces plant growth. Of potential concern is the accumulation of zinc and copper in soil. Table 5.56 describes average mineral content of poultry litter.

The zinc and copper levels in manure are directly related to diet inclusion levels. Mineral premixes usually contain around 80 ppm zinc and 10 ppm copper. The bioavailability of trace minerals in the major feed ingredients is largely unknown, and in most situations their contribution is ignored. The major ingredients do however, contain significant quantities of most trace minerals (Table 5.57).

If copper was 100% bioavailable in corn and soybean meal, then there would be little advantage to using supplements. The limited data available on trace mineral availability from work 20 – 40 years old, indicates values of 40 - 70%. The use of phytase further complicates the issue, since some of the minerals present in natural ingredients (Table 5.57) will be present within the phytate molecule. When phytase is used, presumably there is greater bioavailability of minerals such as zinc from corn and soybean meal. There may be up to a 10% increased bioavailability of zinc as a result of using phytase. It seems as though it is theoretically possible to greatly reduce trace mineral supplements in broiler diets, thereby reducing their accumulation in manure.

Trace mineral proteinates, although much more expensive than oxides or sulfates, are of more predictable bioavailability. In using very low levels of trace minerals under experimental conditions, we have recently used such mineral proteinates because of their high and consistent bioavailability. In this study, birds were fed a conventional mineral premix using oxides and sulfates. The supplements were arbitrarily assigned a digestibility value of 70%, and then this level of 'digestible minerals' provided as mineral proteinates. Mineral levels were further reduced by using only 80%→20% of these already reduced concentrations (Table 5.58).

Table 5.56 Trace mineral content of broiler litter

	Mineral (ppm)							
	Zn	***Cu***	***Fe***	***Mn***	***Mg***	***Al***	***Ca***	***Na***
Dry matter	*300*	*500*	*3000*	*400*	*6000*	*2000*	*3000*	*4000*
As is (40% DM)	*120*	*200*	*1200*	*160*	*2400*	*800*	*1200*	*1600*

Table 5.57 Trace mineral content of selected feed ingredients (ppm)

	Zinc	***Manganese***	***Iron***	***Copper***
Corn	*12*	*10*	*107*	*11*
Soybean meal	*37*	*19*	*184*	*15*
Meat meal	*97*	*7*	*285*	*12*
Wheat shorts	*76*	*104*	*203*	*16*

Table 5.58 Broiler performance and calculated mineral output in manure from a farm growing 5 crops of 100,000 male broilers annually

Treatment	0-42 d		Mineral output (kg/yr)			
	Wt gain (g)	F:G	Zn	Mn	Fe	Cu
Inorganics[1]	2217	1.75	470	273	535	19
Bioplex[2]	2351	1.70	318	217	523	17
Bioplex 80%	2239	1.73	294	185	491	18
Bioplex 60%	2285	1.72	309	172	494	16
Bioplex 40%	2185	1.74	299	156	487	16
Bioplex 20%	2291	1.69	292	130	446	15

[1] Zn, 100 ppm; Mn, 90 ppm; Fe, 30 ppm; Cu, 5 ppm
[2] Zn, 70 ppm; Mn, 63 ppm; Fe, 18 ppm; Cu, 3 ppm

Using the 20% inclusion of the mineral proteinate, supplements were Zn, 14 ppm; Mn, 13 ppm; Fe, 3.6 ppm and Cu, 0.6 ppm. Even at these low levels, broiler performance was unaffected. Based on a 3 d total collection period of manure at 18 d and at 39 d, it was possible to predict manure mineral output extrapolated for the 42 d grow-out period (Table 5.58). There was a 37% reduction in zinc output and 21% reduction in copper output in manure. If there is future legislation concerning trace mineral content of manure, much as now exists for N and P in many countries, then it should be possible to reduce levels by nutritional intervention. If such legislation occurs, it will be interesting to see what happens to the current common practice of using high levels of copper as an antibacterial agent.

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CHAPTER 6

FEEDING PROGRAMS FOR BROILER BREEDERS

Page

6.1 Diet specifications and feed formulations

The continuing increase in genetic potential of the broiler chicken poses ever-greater challenges for feeding and managing breeders. Growth and reproductive characteristics are negatively correlated, and because of the relative economic significance of broiler performance within integrated operations, broiler performance is necessarily of primary importance. As appetite and weight for age increase in commercial broilers, so nutrient restriction of young breeders must start at earlier ages and/or be of increasing severity at older ages. The modern breeder hen at 22 weeks of age must be comparable in weight to her offspring at 6 weeks of age. It is, therefore, not too surprising that appetite control of parent flocks is becoming more challenging. Like most other classes of poultry, the absolute requirements of broiler breeders are influenced by both feeding level and diet nutrient specifications. However, this dual effect means that nutrient intake can be controlled much more closely, and so represents great potential for matching intake to requirement. High-yield breeders are often slightly later maturing (7 – 10 d) than are conventional broiler breeders and have a longer feed clean-up time. In general, managers should not react too quickly in changing the feed allocation or diet as they normally would to circumstances arising with conventional breeders. High-yield roosters also pose some interesting new feed management problems, related to their aggressive behaviour. Tables 6.1 and 6.2 show diet specifications for growing and adult breeders, while Table 6.3 provides examples of corn based diets. Tables 6.4, 6.5 and 6.6 indicate nutrient specifications for adult birds as detailed by the primary breeding companies.

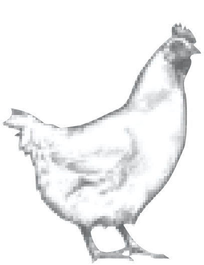


Table 6.1 Diet specifications for broiler breeder pullets

Age (wks)	***Starter* 0 – 4**	***Grower* 4 – 12**	***Developer* 12 – 22**	***Prebreeder* 20 - 22**
Crude Protein (%)	18.5	17.0	16.0	16.0
Metabolizable Energy (kcal/kg)	2850	2850	2850	2850
Calcium (%)	0.95	0.92	0.89	2.25
Available Phosphorus (%)	0.45	0.40	0.38	0.42
Sodium (%)	0.20	0.19	0.17	0.17
Methionine (%)	0.42	0.35	0.32	0.37
Methionine + Cystine (%)	0.80	0.72	0.65	0.64
Lysine (%)	1.00	0.90	0.80	0.77
Threonine (%)	0.72	0.67	0.60	0.58
Tryptophan (%)	0.20	0.18	0.16	0.15
Arginine (%)	1.15	1.00	0.86	0.80
Valine (%)	0.75	0.70	0.65	0.60
Leucine (%)	0.90	0.85	0.92	0.88
Isoleucine (%)	0.70	0.60	0.51	0.48
Histidine (%)	0.20	0.18	0.29	0.26
Phenylalanine (%)	0.65	0.60	0.53	0.49
***Vitamins** (per kg of diet)*				
Vitamin A (I.U.)	8000			
Vitamin D_3 (I.U.)	3000			
Vitamin E (I.U.)	50			
Vitamin K (I.U.)	3			
Thiamin (mg)	2			
Riboflavin (mg)	10			
Pyridoxine (mg)	4			
Pantothenic acid (mg)	12			
Folic acid (mg)	0.75			
Biotin (ug)	100			
Niacin (mg)	40			
Choline (mg)	500			
Vitamin B_{12} (µg)	15			
***Trace minerals** (per kg of diet)*				
Manganese (mg)	60			
Iron (mg)	30			
Copper (mg)	6			
Zinc (mg)	60			
Iodine (mg)	0.5			
Selenium (mg)	0.3			

Table 6.2 Diet specifications for adult broiler breeders

Age (wks)	Phase 1 22 – 34	Phase 2 34 – 54	Phase 3 54 – 64	Male 22 - 64
Crude Protein (%)	16.0	15.0	14.0	12.0
Metabolizable Energy (kcal/kg)	2850	2850	2850	2750
Calcium (%)	3.00	3.20	3.40	0.75
Available Phosphorus (%)	0.41	0.38	0.34	0.30
Sodium (%)	0.18	0.18	0.18	0.18
Methionine (%)	0.36	0.32	0.30	0.28
Methionine + Cystine (%)	0.65	0.62	0.59	0.55
Lysine (%)	0.80	0.74	0.68	0.55
Threonine (%)	0.62	0.61	0.57	0.51
Tryptophan (%)	0.18	0.16	0.14	0.13
Arginine (%)	0.90	0.82	0.74	0.65
Valine (%)	0.60	0.55	0.50	0.46
Leucine (%)	0.80	0.74	0.70	0.64
Isoleucine (%)	0.62	0.58	0.52	0.45
Histidine (%)	0.18	0.17	0.16	0.12
Phenylalanine (%)	0.55	0.50	0.45	0.40
Vitamins (per kg of diet)				
Vitamin A (I.U.)	8000			
Vitamin D_3 (I.U.)	3000			
Vitamin E (I.U.)	75			
Vitamin K (I.U.)	3			
Thiamin (mg)	2			
Riboflavin (mg)	10			
Pyridoxine (mg)	4			
Pantothenic acid (mg)	12			
Folic acid (mg)	0.75			
Biotin (ug)	100			
Niacin (mg)	40			
Choline (mg)	500			
Vitamin B_{12} (µg)	15			
Trace minerals (per kg of diet)				
Manganese (mg)	90			
Iron (mg)	30			
Copper (mg)	12			
Zinc (mg)	100			
Iodine (mg)	0.5			
Selenium (mg)	0.3			

Table 6.3 Example of breeder diets (kg)

	Starter	Grower	Developer	Prebreeder	Breeder 1	Male
Corn	487	538	539	600	666	455
Wheat shorts	264	250	280	154	45	367
Wheat bran						100
Soybean meal	213	178	148	178	201	52
DL-Methionine*	2.3	1.9	1.6	1.3	1.3	1.7
L-Lysine	0.8	0.9	0.6			0.2
Salt	3.8	3.5	3	3.1	3.4	3.3
Limestone	16.6	17.2	18	51	70.5	17
Dical Phosphate	11.5	9.5	8.8	11.6	11.8	2.8
Vit-Min Premix**	1	1	1	1	1	1
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	18.5	17.0	16.0	16.0	16.0	13.4
ME (kcal/kg)	2850	2893	2895	2850	2850	2750
Calcium (%)	0.95	0.93	0.93	2.25	3.00	0.75
Av Phosphorus (%)	0.45	0.40	0.38	0.42	0.41	0.30
Sodium (%)	0.20	0.19	0.17	0.17	0.18	0.18
Methionine (%)	0.53	0.47	0.42	0.41	0.41	0.38
Meth + Cystine (%)	0.80	0.72	0.65	0.64	0.65	0.55
Lysine (%)	1.00	0.90	0.80	0.78	0.80	0.55
Threonine (%)	0.75	0.70	0.65	0.67	0.69	0.52
Tryptophan (%)	0.25	0.23	0.21	0.22	0.22	0.19

** or equivalent MHA*
*** with choline*

Table 6.4 Nutrient specifications for breeder diets[1] (Management Guide Data)

	Hubbard	Cobb	Ross
Metabolizable energy (kcal/kg)	2865	2860	2860
Crude protein (%)	15.5	16.0	16.0
Calcium (%)	3.2	2.9	3.0
Av. Phosphorus (%)	0.40	0.45	0.40
Sodium (%)	0.17	0.17	0.16
Linoleic acid (%)	1.25	1.5	1.25
Methionine (%)	0.35	0.35	0.35
Meth + cystine (%)	0.58	0.64	0.61
Lysine (%)	0.71	0.78	0.83
Tryptophan (%)	0.17	0.17	0.21
Vitamin A (TIU/kg)	8.8	11.0	5.45
Vitamin D_3 (TIU/kg)	3.3	1.75	1.6
Vitamin E (IU/kg)	44	40	45
Vitamin K_3 (mg/kg)	3.3	5.0	2.0
Thiamin (mg/kg)	4.4	2.5	3.0
Riboflavin (mg/kg)	8.8	10.0	5.5
Pantothenate (mg/kg)	15.5	20.0	7.0
Niacin (mg/kg)	53	45	18
Pyridoxine (mg/kg)	3.3	5.0	2.0
Choline (mg/kg)	660	186	450
Folic acid (mg/kg)	1.0	1.25	0.90
Biotin (mg/kg)	0.22	0.20	0.20
Vitamin B_{12} (µg/kg)	11	20	20
Manganese (mg/kg)	80	90	30
Zinc (mg/kg)	80	75	40
Iron (mg/kg)	66	20	30
Copper (mg/kg)	9	3.6	4
Iodine (mg/kg)	1.1	1.5	0.46
Selenium (mg/kg)	0.30	0.13	0.10

[1]Phase I, if more than one diet recommended

Table 6.5 Breeder diet specifications for amino acids expressed per unit of protein or per unit of energy

	Hubbard	Cobb	Ross
Methionine			
(g/kg CP)	22.5	22.2	21.3
(g/Mcal)	1.26	1.20	1.19
Meth + Cys			
(g/kg CP)	37.4	40.0	36.3
(g/Mcal)	2.02	2.20	2.03
Lysine			
(g/kg CP)	45.8	48.8	50.0
(g/Mcal)	2.47	2.68	2.80
Tryptophan			
(g/kg CP)	10.9	10.6	11.3
(g/Mcal)	0.59	0.58	0.63

Table 6.6 Daily intake of selected nutrients for breeders at 28 weeks of age[1]

	Hubbard	Cobb	Ross
Energy (kcal)	458	469	478
Crude protein (g)	24.8	25.8	26.7
Calcium (g)	5.1	4.7	5.0
Av. Phosphorus (mg)	640	724	668
Methionine (mg)	560	563	567
Meth + cys (mg)	928	1030	967
Lysine (mg)	1136	1256	1336
Feed intake (g)	160	161	161
Body Weight (g)	3100	3130	3150

[1]*Calculated from Management Guide Data*

6.2 Breeder pullet feeding programs

Pullets and roosters must be managed so as to achieve the desired uniform weight at time of photostimulation, which is usually around 22 – 24 weeks of age. Growth and uniformity are influenced by feeding program and to a lesser extent, feed formulation. Within reason, it is possible to achieve the desired weight for age when using diets with a vast range of nutrient specification. Nutrient intake is largely controlled by the degree of feed restriction. For example, it is theoretically possible to grow pullets on diets with energy levels ranging from 2600-3100 kcal ME/kg. In practice, diet energy level is usually within the range of 2750-2950 kcal ME/kg, although for diets necessarily formulated outside of this range, energy intake can be controlled by adjusting feed intake. It is usually more difficult to maintain uniformity with high-energy diets, since this necessarily implies much smaller quantities of feed being distributed at any one time. General standards for growth and feed intake are shown in Table 6.7.

Table 6.7 Standards for pullet and rooster growth and development

Age (wks)	Pullets B. wt. (g)	Pullets Feed intake[1] (g/d)	Pullets Uniformity (%)	Roosters B. wt. (g)	Roosters Feed intake[1] (g/d)	Roosters Uniformity (%)
1	120	25	75	125	27	70
2	230	27	75	280	30	70
3	330	29	75	440	32	70
4	420	31	80	610	34	75
5	510	34	80	720	36	75
6	610	36	80	840	39	75
7	680	40	80	930	42	75
8	760	43	80	1040	46	80
9	860	46	80	1180	50	80
10	960	49	80	1300	53	80
11	1050	53	80	1420	55	80
12	1150	58	80	1550	58	80
13	1250	62	80	1700	63	80
14	1350	66	85	1880	66	82
15	1450	68	85	2060	70	82
16	1550	71	85	2200	76	82
17	1670	76	85	2320	81	85
18	1790	82	85	2450	90	85
19	1900	88	90	2600	95	85
20	2040	94	90	2830	100	85
21	2200	98	90	2970	105	85
22	2320	102	90	3100	110	85

[1]*Mean diet ME 2900 kcal/kg*

Each commercial strain is going to have characteristic patterns of growth and these can be used to dictate feeding program. These strains will have an 'optimum' mature weight which is around 2.2 kg for pullets and 3.1 kg for roosters at 22 weeks of age. Interestingly as broiler growth potential has increased continuously over the last 20-30 years, the mature weight of breeders has changed very little. With the potential to influence nutrient intake with both diet modification and degree of feed restriction, it is obvious that target weights can be achieved by various routes, and these will influence rearing (feed) costs. Over the years, both qualitative and quantitative nutrient restriction programs have been studied.

a) Qualitative feed restriction

Theoretically, it should be possible to control growth of juvenile breeders by providing either low nutrient dense diets and/or formulating diets with marginal deficiencies of certain nutrients. It is impossible to achieve the desired growth rate of birds simply by feeding low nutrient dense diets. The bird's voracious appetite means that it can growth quite well on diets as low as 2300 - 2400 kcal ME/kg, on an *ad-lib* basis, and so diets of less than 2000 kcal ME/kg are probably required to limit growth. Such diets are very expensive per unit of energy, are expensive to transport, and result in very wet litter.

Diets that are borderline deficient in protein and amino acids will limit growth. In most instances, such programs have failed since not all birds in a flock have identical nutrient requirements. For example, reducing the methionine content of the diet by 25% may well lead to a reduction in mean flock weight. Unfortunately, those birds with a high inherent methionine requirement will be very light in weight, while those birds with an inherently low methionine requirement will be little affected by the diet and grow at a normal rate. Therefore, while mean flock weight can often be manipulated with qualitative feed restriction, uniformity of flock weight is usually very poor, often reaching 30 – 40% compared to 80% under ideal conditions (% of birds ± 15% of flock mean weight). For example, our studies with salt deficient diets indicated that mean flock weight could be quite accurately controlled by regulating the level of salt added to a corn-soybean meal based diet. Unfortunately, flock uniformity at 20 weeks was very low, and consequently many birds were over- or under-weight in the breeder house and both egg production and fertility were impaired. Similar attempts at qualitative feed restriction have been made with manipulation of fatty acid and amino acid levels in the diet.

b) Quantitative feed restriction

Some type of physical feed restriction is universally used to control breeder growth. The traditional system has been skip-a-day where, as its name implies, birds are fed only on alternate days. An example skip-a-day program is shown in Table 6.8.

Table 6.8 Skip-a-day feed restriction program for pullets and roosters (diet at 2900 kcal/kg)

Age (wks)	*Pullets (g)*	*Roosters (g)*
1	Ad-lib	Ad-lib
2	Controlled 25/d	Controlled 30/d
3	Controlled 30/d	Controlled 40/d
4	70	80
5	80	90
6	90	100
7	100	110
8	105	115
9	110	120
10	115	125
11	120	130
12	125	135
13	130	140
14	135	145
15	140	150
16	145	155
17	155	160
18	165	170
19	175	180
20	185	190

The skip-a-day feed intake will obviously depend upon nutrient density and environmental conditions, yet these values can be used as guidelines. The concept of feeding to body weight and the regulation of body weight will be discussed more fully in a subsequent section. Table 6.8 indicates a restricted feeding program for both pullets and cockerels to be initiated at 4 weeks of age. Prior to this, 'controlled' feeding should be practiced so as to acclimatize birds to a limited feed intake. Controlled feeding should be adjusted to ensure that birds are cleaning up their feed on a daily basis within 4 – 6 hours. Because different strains of birds have different growth characteristics, then initiation of controlled and restricted feeding must be flexible in order to control body weight. For strains with inherently fast early growth rate, restricted feeding on a daily basis may be necessary as early as 7 – 10 d of age. For other strains, *ad-lib* feeding to 3 – 4 weeks is possible since they have a slow initial growth rate.

With skip-a-day, birds are given these quantities of feed only every other day. The concept behind this program is that with every other day feeding, birds are offered a considerable quantity of feed and this is easier to distribute so that even the smallest most timid bird can get a chance to eat. The usual alternative to skip-a-day feeding is feeding restricted quantities every day. For example, at 11 weeks of age, pullets could be fed 60 g each day. The problem with every day feeding is that feed is eaten very quickly and so all birds within a flock may not get ade-

quate feed. With such small quantities of feed, and using slow-speed feed chains or auger delivery, it is not unheard of for birds to 'keep-up' with feed delivery close to the feed hoppers, and reduce effective feeder space. With every-day feeding, birds may well consume their daily allocation within 30 minutes, and so adequate feeder space is essential with this type of program. However, there is a trend towards every day feeding since it is more efficient and with good management and supervision, good uniformity can be achieved. Improved efficiency results from birds utilizing feed directly each day, rather than there being the inherent inefficiency of skip-a-day fed birds having to utilize stored energy for maintenance on the off-feed day. Most daily feed allowances are derived by halving corresponding skip-a-day programs. For example in Table 6.8, the skip-a-day allowance for a 9 week pullet is 110 g. If pullets are given 55 g daily, they will gain more weight since they use this feed more efficiently. In practice, skip-a-day allowances have to be divided by about 2.2 (rather than 2) in order to achieve the same growth rate. Table 6.9 shows growth rate of pullets and roosters fed skip-a-day or exactly 50% of this allowance on a daily basis. Birds fed daily at 50% of the skip-a-day allowance are consistently 8 – 10% heavier.

Whatever system of feed restriction is used, the goals are to obtain uniform and even growth rate through to maturity. Ideally the pullets and roosters will be close to target weight by 16 – 17 weeks of age, since attempts at major increases (or decreases) in growth after this time often compromise body composition, maturity and subsequent reproductive performance.

Some flocks will invariably get heavier than the desired standard and their growth rate has to be tempered more than normal. It is tempting to drastically reduce the feed intake of such flocks, so as to quickly correct the excess growth. Such action is usually accompanied by loss in uniformity. Overweight flocks must be brought back to standard more slowly, perhaps over 6 - 8 weeks depending on age. Underweight flocks are more easy to manage, since it is easy to give more feed. However, it is again necessary to correct the flock by a gradual increase in feed allowance, such that desired body weight is realized within 3 – 4 weeks. Table 6.10 shows examples of records from actual breeder flocks each of about 40,000 pullets, that were over or underweight at either 6 or 13 weeks of age. Weight readjustment, achieved by altering feed allowance, occurred slowly to maintain uniformity within these flocks.

Table 6.9 Effect of providing equal quantities of feed by skip-a-day or every day feeding on growth of pullets and roosters

Pullet weight[1] (g)			*19 wk Rooster weight[2] (g)*		
Age (wks)	*Skip-a-day*	*Every day*	*Diet treatment*	*Skip-a-day*	*Every day*
8	530[b]	790[a]	2850 ME, 15% CP	2410	2530
11	950[b]	1010[a]	2850 ME, 20% CP	2320	2510
14	1190[b]	1290[a]	2000 ME, 15% CP	1960	2150
17	1540[b]	1630[a]	2000 ME, 20% CP	1920	2040
20	1890[b]	1980[a]			

[1]*Adapted from Bennett and Leeson (1989);* [2]*Adapted from Vaughters et al. (1987)*

Table 6.10 Body weight goals for pullets that become overweight or underweight at 6 or 13 wks of age

Age (wks)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Standard wt. (kg)	.12	.23	.33	.42	.51	.61	.68	.76	.86	.96	1.05	1.15	1.25	1.35	1.45	1.55	1.67	1.79	1.90	2.04
Flock #1 Overweight at 6 wks						.75	.81	.88	.97	1.06	1.15	1.24	1.34	1.43	1.52	1.61	1.73	1.84	1.95	2.09
Flock #2 Underweight at 6 wks						.50	.58	.69	.80	.91	1.02	1.15	1.25	1.35	1.45	1.55	1.67	1.79	1.90	2.04
Flock #3 Overweight at 13 wks													1.40	1.49	1.58	1.67	1.79	1.90	2.01	2.14
Flock #4 Underweight at 13 wks													1.10	1.22	1.35	1.48	1.62	1.75	1.90	2.04

Table 6.11 Examples of alternate feed programs to prevent choking in 15 – 18 week old breeder pullets (g feed/bird/day equivalent to 80 g/bird/day)

	Day									
System	1	2	3	4	5	6	7	8	9	10
Skip-a-day	160	0	160	0	160	0	160	0	160	0
2 – 1	120	120	0	120	120	0	120	120	0	120
3 - 1	106	106	106	0	106	106	106	0	106	106
6 - 1	93	93	93	93	93	93	0	93	93	93

Choking and death can sometimes occur with breeders at 14 – 18 weeks when fed skip-a-day. Assuming that there is adequate feeder space, then this program can only be resolved by changing the program so as to give smaller quantities of feed at any one time. Example programs are shown in Table 6.11, where the standard is 'equivalency' of 80 g/bird/day. Changing to one of these programs also helps in the transition from skip-a-day to daily feeding as adults.

Whatever system is used, there needs to be flexibility related to status of the flock as affected by various management decisions. Certain vaccinations and the physical movement of birds can cause a 1 – 2 day delay in growth rate. These periods of known stress should be counteracted by extra feeding. For example, if skip-a-day fed birds are scheduled to be moved on day 6 as shown in Table 6.11 (non feed day), then birds should be given feed this day regardless of the preplanned schedule.

Coccidiosis is an ever present problem when rearing breeder pullets on litter. Because anticoccidials are not usually allowed in adult breeder diets, the bird must develop immunity during rearing. Such immunity does not develop with anticoccidials commonly used for commercial broilers, and in particular the ionophores. This means that if ionophores are used during rearing of breeder pullets, they will most likely prevent clinical coccidiosis, but these birds may develop clinical symptoms as soon as they are transferred to the breeder house. If an anticoccidial is used during rearing, then products such as amprolium are more advantageous. Compounds like amprolium usually prevent acute clinical symptoms, while at the same time, allowing some build-up of immunity. In certain countries, depending upon feed regulations, amprolium can be used throughout the life-cycle of the bird. An alternate approach, and one that requires superior management skills, is to use non-medicated feed during rearing, and to treat birds as soon as clinical symptoms occur. Since treatment must be immediate, only water-dispensable products, such as amprolium, are recommended. It is now more common to vaccinate chicks with attenuated live vaccines. Chicks are sprayed at the hatchery and immunity should develop during early rearing.

c) *Specific programs for roosters*

Roosters can be grown with the hens or grown separately, but in both situations they will almost exclusively be fed starter and grower diets designed for the female birds. This poses no major problem, because there are no large differences in nutrient requirements of the sexes up to the time of maturity. Where males and females are grown together, the onset of restriction programs and general feed allocation systems are usually dictated by progress in hen weight and condition. Male growth and condition cannot be controlled as well under these situations, and this has to be an accepted consequence of this management decision.

Growing roosters separately provides the best opportunity to dictate and control their development. As with commercial broilers, the male breeders will respond more to high protein starter diets or to more prolonged feeding of these diets. The opposite situation also applies, in that male breeder chicks will be more adversely affected by low protein or low amino acid starter diets. For example, under ideal conditions, a well-balanced 16% CP diet can be used as a starter for female chicks and this results in slower early growth rate with the added advantage of delay in introducing restricted feeding. Male chicks can also be grown on

such diets, although it is not usually recommended, because there will be poorer early feathering and perhaps more uneven growth rate. These problems resolve themselves over time, but as a general rule it is better to start male breeder chicks on at least a 17 – 18% CP diet. The male breeder chick is also more sensitive to the effects of low protein diets that contain anticoccidials, such as monensin. Again, poor feathering will result if starter diets contain much less than 18% CP. Poor early feathering has no long lasting effect on subsequent breeder performance, although the chicks obviously look different and they may suffer more from early cold stress.

As for the hens, it is usual to start feed restriction of rooster chicks at around 3 weeks of age. Starting at 3 weeks of age, groups of 10 chicks can be weighed together to give an idea of body weight and controlled feeding started. Starting at 4 weeks of age, sample birds should be weighed individually, just as occurs with the hens, and mean weight and uniformity plotted to give a visual image of flock progress. Ideally, feed allocation will be increased on a weekly basis, although this should be dictated by the weekly body weight measurements. Changes in environmental temperature or unprogrammed changes in diet energy (due to ingredient variability, etc.) will affect nutrient needs, feed intake and/or growth rate. Usually the body weight and uniformity of the birds represents their true feed needs at that time and so there needs to be flexibility in feed allocation to account for these variables.

Skip-a-day feeding is usually the preferred system up to time of transfer to the breeder house. However in some situations, choking can occur with males after 14 – 16 weeks of age, and this is caused by rapid and excessive feed intake on feeding days. Such choking causes 0.5% mortality per day in extreme situations, but can sometimes be resolved by ensuring that water is available for at least 1 hour prior to feeding. Where this technique fails to correct the problem, it may be necessary to change to a 5:2 or even a 6:1 feeding program as previously described for females. These programs provide the same amount of feed on a weekly basis, but this is given as smaller quantities, more often. There seems to be less gorging when birds eat smaller quantities of feed more often. A potential problem with changing to 5:2 or 6:1 feeding programs is loss of uniformity, because daily feeding time will be very short. If males are grown separately from females, then this uniformity problem can sometimes be resolved by changing to a lower nutrient density diet, and giving proportionally more feed so as to maintain normal nutrient intake (however under these conditions, daily feed intake will still be less than with skip-a-day feeding). Whatever feeding system is used, it is essential to provide adequate feeder space such that all birds can eat at one time.

d) Water management

Some type of water restriction program is also important for juvenile breeders. With feed restriction, birds can consume their feed in 30 minutes to 2 hours depending upon the system and age of bird. Given the opportunity, these birds will consume excessive quantities of water simply out of boredom or to satisfy physical hunger. Certainly birds given free access to water seem to have wetter litter, and there is no doubt that a water restriction program is necessary in order to maintain good litter quality and help prevent build-up of intestinal parasites and maintain foot pad condition. Various water restriction programs are used and there are no universal guidelines that should be adhered to. Pullets develop normally when given as little as half hour access to water each day, although longer periods than this are usually recommended. It seems advisable to give birds one half to 1 hour access to water prior to feed delivery, especially with skip-a-day

feeding. The reason for this is prevention of sudden-death type syndrome that occurs with a small proportion of birds that invariably have grossly distended crops full of dry feed. The exact cause of death is unknown although it is possible that the sudden intake of a large volume of dry feed acts as a 'sponge' to normal body fluids and so upsets the bird's water/electrolyte balance. Giving birds access to water prior to feed delivery often seems to resolve this problem. Table 6.12 provides general recommendations for water access. These values should be considered as guidelines only, and during periods of heat stress or during disease conditions and around the time of moving etc., time allocations should be increased. With skip-a-day feeding, it is usual to more severely limit water access on off-feed days based on the assumption that birds tend to drink most water on this day (due to boredom or need to meet physical intake satiety) since they are without feed. However, our studies suggest that breeder pullets drink most water on feed days, and seem generally uninterested in water on off-feed days (Table 6.13).

Table 6.12 Suggested water access time for juvenile breeders

	Feed Day		*Off-feed Day*	
	am	*pm*	*am*	*pm*
Skip-a-day feeding	*2-3 hr, starting 1 hr prior to feeding*	*1 hr*	*1 hr*	*1 hr*
Every day feeding	*2 hr, starting 1 hr prior to feeding*	*1 hr*	-	-

Table 6.13 Total water usage of 13-week old skip-a-day or daily fed birds with free or restricted access to water (ml/bird/day)

	Skip-a-day fed birds			*Daily fed birds*
	Water restricted each day	*Water restricted on feed days*	*Free access to water*	*Free access to water*
Feed day	*192*	*196*	*273*	*205*
Off-feed day	*122*	*122*	*37*	*217*
Mean intake	*157*	*161*	*155*	*211*
Water:feed	*2.38*	*2.44*	*2.35*	*3.20*

Adapted from Bennett (1989)

When birds are daily fed, there is a fairly consistent pattern of water intake. With skip-a-day feeding and free access to water, pullets surprisingly consume very little water on an off-feed day – for these birds, the largest water intake occurs on the feed day. If this data can be substantiated under field conditions, it suggests that the major emphasis on water restriction of skip-a-day fed birds should occur on the feed day rather than the off-feed day. These results are perhaps not too surprising in view of the well established relationship between the intakes of water and feed. It also appears as though daily feeding stimulates overall water usage and increases the water:feed ratio. As previously discussed, the major factor influencing water needs, is environmental temperature. At higher temperatures, birds need more water to enhance evaporative cooling. Water restriction programs must therefore be flexible as environmental temperatures change (Table 6.14).

Table 6.14 Daily water consumption of pullets on skip-a-day feeding (litres/1000 pullets)

Age (wks)	*20°C*	*35°C*
4	70	145
6	105	175
8	115	192
10	130	220
12	145	240
14	160	270
16	175	290
18	190	320
20	205	345

6.3 Prebreeder nutrition

There is considerable variation in application and use of prebreeder diets. While most primary breeding companies show specifications for prebreeder diets, there are significant numbers of birds that are changed directly from grower diet to breeder diet. Choice of prebreeder diet and its application must be tailored to individual farm circumstances.

Using a prebreeder diet assumes that the bird's nutrient needs are different at 21 – 24 weeks of age, which is the most common time for feeding such diets. However, apart from considerations for calcium metabolism, it can be argued that any change in the bird's requirements can be accommodated by adjusting the level of feed intake. With commercial egg layers, 'pre-lay' diets usually involve a change in calcium level, in order to establish the bird's calcium reserves necessary for rapid and sudden onset of eggshell production. The same situation can be applied to heavy breeders today, because with flocks of uniform body weight and with good light management, synchronization of maturity leads to rapid increase in egg numbers up to peak production. However, most often prebreeder diets are used in an attempt to 'condition' or correct growth and/or body composition problems that have arisen during the 14 – 18 week growing period. In these situations managers are perhaps ill-informed of the expectations that result from merely changing diet specifications at this time.

Although there is no specific prebreeder 'period', most breeder managers consider the 21 – 24 week period to be the major transition

time for sexual development of the bird. During this time (3 weeks) the pullet is expected to increase in weight by about 450 g. This is somewhat more than the growth expectation of around 400 g for the previous 4 weeks (17 – 21 weeks) but comparable to the 450 g for the 4 weeks from 24-28 weeks of age. It is expected that a significant proportion of this growth will be as ovary and oviduct, which are developing in response to light stimulation. However, there is little evidence to suggest that high nutrient dense diets and/or feed allocation have any meaningful effect on ovary or oviduct development. Studies suggest that the protein requirement of the breeder at this critical time is only around 10 g/bird/day, which is much less than is provided by most prebreeder diets. There is some evidence to suggest that excess protein fed during the late growing/prebreeder period causes an increase in plasma uric acid levels and especially 2 – 3 hours after feeding. Plasma uric acid levels in such birds are similar to those of birds showing articular gout, and so there is concern about excess protein contributing to the potential for leg problems in these young breeders.

A practical complication of this sexual development, is that it invariably coincides with moving the pullets from grower to breeder facilities. During transportation over long distances or during heat stress, etc., birds can lose up to 100 g of body weight at this critical time. If weight loss does occur during transportation, then pullets should be given an extra feeding. For example, pullets should be moved on an 'off-feed' day, but they should nevertheless be fed that day in the breeder house after all birds are housed. Weight loss cannot be allowed at this critical time, and so the question to be answered is – do prebreeder diets help in this physical move, as well as prime the bird for sexual maturity? Development of the ovary and oviduct requires both protein/amino acids and energy (fat accretion). Nutrients of interest, therefore, are protein and energy, together with an increase in calcium for early deposition of medullary bone. It has never been clearly established that such nutrients need to come from a specially fortified diet versus simply increasing the feed allowance of the grower diet or breeder diet that is introduced prior to maturity. Following are factors to consider in feeding the bird in the prebreeder transition period, and the need or not for specialized diets.

a) Calcium metabolism

Prebreeder diets can be used to pre-condition the pullet for impending eggshell production. The very first egg represents a 1.5 – 2.0 g loss in calcium from the body, the source of which is both feed and medullary bone reserve. Breeder hens today are capable of a sustained long clutch length which is necessary to achieve potential peak production at 85 – 87%. Calcium metabolism is, therefore, very important for the breeder. With Leghorn hens the consequence of inadequate early calcium balance is cage layer fatigue. Breeders do not show such signs, because they naturally have more exercise, and also have a readily available alternate source of diet calcium in the form of their flockmates' eggs. Hens have an innate ability to seek diet calcium in any source and so improperly fed breeders will eat litter and eggshells in an attempt to balance their diet. However, inadequate calcium in the diet does lead to disruption of ovulation, and so these birds stop laying until their meager calcium reserves are replenished. In a breeder flock, it is the larger bodied, early maturing pullets that are disadvantaged in this manner. Commercially, three different approaches are used in prebreeder calcium nutrition.

Firstly, is the use of grower diets that contain just 0.9 - 1.0% calcium being fed up to 5% egg production. This is the system that was used many years ago. At 5% egg production, 100% of the flock is not producing at 5% egg production – rather closer to 5% of the early maturing heavier pullets are producing at almost 100% production. Pullets can produce just 2 – 3 eggs with a diet containing 1% calcium. After this time they will eat litter and/or eggs as previously described, or more commonly, they simply shut down the ovary. With this approach, the flock may in fact be at 10 – 15% production before the breeder diet is introduced, since no farm system allows for instantaneous change in feed supply because feed tanks are hopefully never completely empty. While delayed introduction of the breeder diet may therefore disadvantage early maturing birds, there is one specific situation where this approach seems beneficial. Certain strains, sometimes exhibit high mortality, reaching 1% weekly from 25 – 30 weeks of age. The condition is referred to as calcium tetany or SDS and seems to reflect the consequences of hypocalcemia, being somewhat similar to milk fever in dairy cows. It is most common in non-uniform flocks when either breeder or moderately high calcium prebreeder diets are fed for 4 – 6 weeks prior to maturity. The condition can usually be prevented by using a low calcium (max 1%) grower diet to 1% egg production. When calcium tetany occurs, the severity can be minimized by feeding large particle limestone at 3 g/b/d for three consecutive days, ideally in the late afternoon.

The second alternative for calcium feeding at this time involves the classical prebreeder diet containing around 1.5% calcium, which is really a compromise situation. It allows for greater medullary bone reserves to develop, without having to resort to the 3.0% calcium as used in a breeder diet. However 1.5% calcium is still inadequate for sustained eggshell production – with this diet the breeder can produce 4 – 6 eggs before the ovulation pattern is affected. If a prebreeder diet is used therefore, and a moderate calcium level is part of this program, then the diet must be replaced by the breeder diet no later than at 5% production.

The third option is perhaps the most simple solution, and involves changing from grower to breeder at first egg (10 days before 1% production). Having the breeder diet in place before maturity, ensures that even the earliest maturing birds have adequate calcium for sustained early egg production. Proponents of prebreeder diets suggest that breeder diets introduced early provide too much calcium and that this contributes to kidney disorders, because the extra ingested calcium must be excreted in the urine. There is an indication that feeding adult breeder diets for 10 – 12 weeks prior to maturity can adversely affect kidney function, especially if birds are also challenged with infectious bronchitis. However feeding 'extra' calcium for two to three weeks prior to maturity has no such effect. It is also interesting to realize that most roosters today are fed high calcium breeder diets, which provide 4 – 6 times their calcium needs, yet kidney dysfunction is quite rare in these birds. Early introduction of the breeder diet is not recommended when farms have a history of high mortality due to calcium tetany.

b) Considerations of body weight and stature

Body weight and body condition of the bird around the time of maturity, are perhaps the most important criteria that will ultimately influence breeder performance. These parameters should

not be considered in isolation, although at this time we do not have a good method of readily assessing body condition. Each strain of bird has a characteristic mature body weight that must be reached or surpassed for adequate egg production and egg mass output. In general, prebreeder diets should not be used in an attempt to manipulate mature body size. The reason for this is that with most flocks it is too late at this stage of rearing (21 – 24 weeks) to meaningfully influence body weight. However, if birds are underweight when placed in the breeder house, then there is perhaps a need to manipulate body weight prior to maturity. Under controlled environmental conditions, this can some- times be achieved by delaying photostimulation. If prebreeder diets are used in an attempt to correct rearing mismanagement it seems as though the bird is most responsive to energy. This fact fits in with the effect of estrogen on fat metabolism, and the significance of fat for liver and ovary development at this time. While higher nutrient density prebreeder diets may be useful in manipulating body weight, it must be remembered that any late growth spurt (if it occurs) will not be accompanied by any meaningful change in skeletal growth. This means that in extreme cases, where birds are very small in weight and stature at 18 – 20 weeks of age, the end result of using high nutrient dense prebreeder diets may well be development of pullets with correct body weight, but of small stature. These short shank length breeders seem more prone to prolapse/pick-out, and so this is another example of the limitations in the use of high density prebreeder diets.

Use of high nutrient dense prebreeder diets to manipulate late growth of broiler breeder pullets does, however, seem somewhat redundant. The reason for this is that with restricted feeding programs, it is more logical to increase feed allowance than to add the complexity of introducing another diet. The only potential problem with this approach is that in extreme cases, feed intake is increased to a level that is in excess of the initial allowance of the breeder diet at start of lay. This can be a potential problem because breeders should not be subjected to a step down in feed allocation prior to peak production.

c) Considerations of body composition

While body composition at maturity may well be as important as body weight at this age, it is obviously a parameter that is difficult to measure. There is little doubt that energy is likely the limiting nutrient for egg production, and that at peak production, feed may not be the sole source of such energy. Labile fat reserves at this time are, therefore, essential to augment feed sources. These labile fat reserves become critical during situations of heat stress or general hot weather conditions. Once the bird starts to produce eggs, then its ability to deposit fat reserves is greatly limited. If labile fat reserves are to be of significance, then they must be deposited prior to maturity. There is obviously a fine balance between ensuring adequate labile fat depots vs. inducing obesity and associated loss of egg production.

d) Considerations for subsequent egg weight and hatchability

Egg size is influenced by the size of the yolk that enters the oviduct. In large part yolk size is influenced by body weight of the bird, and so factors described previously for body weight can also be applied to concerns with egg size. There is a general need for as large an early egg

size as possible. Increased levels of linoleic acid in prebreeder diets may be of some use, although levels in excess of the regular 1% found in most diets produce only marginal effects on early egg size. From a nutritional standpoint, egg size can best be manipulated with diet protein and especially methionine concentration. It is logical, therefore, to consider increasing the methionine levels in prebreeder diets. For these diets, DL-methionine and Alimet® are comparable and both promote maximum early egg size. Early egg size can also be increased by more rapid increase in feed allocation. However such practice is often associated with more double yolked eggs and erratic ovulation resulting in yolks falling into the body cavity.

Eggs from young breeders have lower than ideal hatchability and to some extent this relates to egg composition. The reason for this early hatch problem is not fully resolved, but most likely relates in some way to maturity and development of embryonic membranes and their effect on transfer of nutrients from the yolk to the embryo. There may also be a problem of inadequate transfer of vitamins into the egg although simply increasing vitamin levels in prebreeder diets does not seem to resolve this problem. For a number of critical B vitamins, their concentration in successive eggs does not plateau until after 7 – 10 eggs have been laid. The effect of prebreeder nutrition on these factors warrants further study, but at this time these problems cannot be resolved by simply overfortifying prebreeder diets with vitamins, certain fatty acids or amino acids.

Prebreeder diets can successfully be used as part of a feeding program aimed at maximizing production potential in young breeders. However any desired increase in nutrient intake prior to maturity can most easily be achieved by simply increasing the feed allowance of either grower or adult breeder diet at this time. If prebreeder diets are used, then 21 – 24 weeks seems the most ideal time, assuming 1% production will occur at around 24 weeks of age.

6.4 Breeder hen feeding programs

Adult breeders must be continued on some type of restricted feeding program. After 22 weeks of age, regardless of rearing program, all birds should be fed on a daily basis. General goals for male and female breeders are shown in Table 6.15.

Data from flocks around the world, housed under various conditions and fed varying types of diet indicate that better performance is invariably achieved when body weight gain is optimum through the late rearing-prebreeder early-breeder transition period. The key nutrient under these conditions is most likely energy, because as with the Leghorn pullet, the broiler breeder is in a somewhat delicate balance regarding energy input and energy expenditure. There is considerable variation in suggested energy requirements for the breeder at this time of early egg production. In fact, reported values vary from 400 – 500 kcal/bird/day.

In attempting to rationalize this obvious range of recommendations, energy requirements were calculated for a commercial strain of broiler breeder (Table 6.16). In these calcul-

Table 6.15 Guidelines for mature breeders

Age (wks)	*Body weight (g)* ♀	*Body weight (g)* ♂	*Feed intake[1] (g/b/d)* ♀	*Feed intake[1] (g/b/d)* ♂	*Egg Production* %	*Hatchability* %	*Cumulative* *Hatching eggs*	*Cumulative* *Saleable chicks*
22	2320	3100	110	120	-	-	-	-
24	2550	3270	125	123	5	-	-	-
26	2800	3500	135	125	35	80	2	1.6
28	3100	3650	145	128	75	84	10	8.4
30	3250	3820	150	130	85	88	20	17.2
32	3300	4000	150	130	85	90	32	28.0
34	3350	4100	150	132	84	92	42	37.2
36	3400	4200	148	132	82	92	55	49.2
40	3450	4250	146	132	78	90	75	67.2
44	3500	4300	144	134	74	88	95	84.8
48	3550	4350	142	134	70	86	115	102.0
52	3600	4400	140	134	66	85	130	114.8
56	3650	4450	139	136	62	84	145	125.5
60	3700	4500	138	136	58	82	160	137.8
64	3750	4550	137	136	55	80	174	144.0

[1]*Diet ME 2850 kcal/kg*

Table 6.16 Comparison of calculated energy requirement and feed allowance for the breeder pullets. (Units are kcal ME equivalents)

Age (wks)	*Body wt. (kg)*	*Total maintenance (kcal)*	*Growth (kcal)*	*Eggs (kcal)*	*Total daily energy req. (kcal)*	*Highest feed allowance (kcal)*
20	2.07	235	85	-	320	250
21	2.17	245	85	-	330	315
22	2.27	255	105	-	360	330
23	2.39	260	105	-	365	350
24	2.67	290	110	10	410	380
25	2.80	300	90	20	410	420
26	2.91	305	75	40	420	440
27	3.00	310	50	60	420	470
28	3.06	315	30	80	425	480

ations, values for maintenance energy requirements were extrapolated from our work with breeders. A subsequent factor of 0.82 was used in conversion to ME. An arbitrary 35% activity allowance was included, while growth was assumed to require 5.8 kcal ME/g (50:50, fat:muscle). As shown in Table 6.16 there is concern over the calculated energy requirement in relation to feed allowance, even at the highest feeding level recommended by the management guide. These results suggest that the breeder is in a very precarious situation with regard to energy balance at the critical time of sexual maturity.

This problem of energy availability may well be confounded by the nutritionist's overestimation of that portion of diet energy available to the broiler breeder. Most energy levels of diets and/or ingredients, when assayed, are derived using Leghorn type birds. Work at Guelph indicates that broiler breeders are less able to metabolize diet energy, than are Leghorn birds (Table 6.17). Regardless of diet specifications, it would appear that broiler breeders metabolize about 2.5% less energy from feeds than do Leghorns. This relates to some 70 kcal/kg for most breeder diets. Deficiencies of energy around the time of peak egg production will likely reduce egg production at this time, or as often happens in commercial situations, production will decline some 2 – 3 weeks after peak, when a characteristic 'dip' in production is seen. It is concluded that optimum breeder performance will occur when the bird is in positive energy balance, and sufficient energy is available for production.

With energy intakes of 325, 385, or 450 kcal ME/bird/day, Spratt (1987) observed the following partitioning of diet energy intake during a 24 – 40 week laying period (Table 6.18).

It is interesting to observe that even with relatively low energy intakes birds still produce a reasonable number of eggs and still accrue body mass. In fact, proportional partitioning of 'retained' energy into growth or eggs was little affected by energy intake. It is tempting to speculate that energy intake is the controlling factor of egg production of breeders. If this is correct, then it is suggested that the following model applies for the response of the breeder to energy intake (Figure 6.1).

Fig. 6.1 Schematic representation of adult breeder's response to diet energy intake.

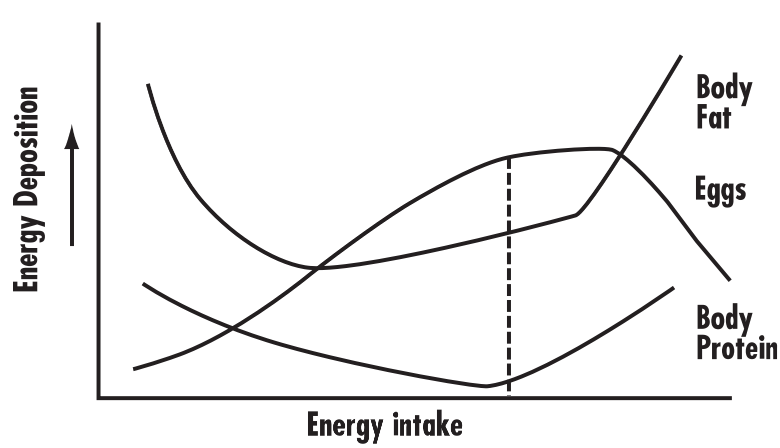


Table 6.17 Diet ME determined with Leghorn and broiler breeder pullets

	Diet ME (kcal/kg)		
Diet type	***Leghorn***	***Broiler breeder***	□
20% CP, 2756 ME	*2805*	*2736*	*-2.5%*
14% CP, 2756 ME	*2847*	*2806*	*-1.5%*
16% CP, 2878 ME	*2976*	*2906*	*-2.4%*
15% CP, 2574 ME	*2685*	*2622*	*-2.4%*

Spratt and Leeson, 1987

Table 6.18 Energy partitioning of broiler breeders (24 – 40 wks)

	Daily energy intake (kcal/bird)		
	High	***Medium***	***Low***
Input as: Feed (kcal)	*60,000*	*51,000*	*42,000*
Output as: Body fat (kcal)	*21,300*	*14,700*	*12,100*
Body protein (kcal)	*0*	*1,900*	*2,400*
Eggs (kcal)	*11,000*	*10,000*	*8,000*
% ME into growth	*36*	*32*	*33*
% ME into eggs	*18*	*20*	*19*

In this scenario, egg production is maximized at a point where some body protein and body fat deposition occurs, i.e. as previously suggested, it is essential that the breeder hen continues to gain weight throughout the laying cycle. Figure 6.1 indicates a fine balance between optimum egg output and development of obesity. As will be discussed later, this balance can best be achieved by monitoring feed allocation according to egg production, egg size, body weight and feed clean-up time. If these calculations of energy metabolism are correct, then it is obvious that energy intake and energy balance are critical to breeders that are expected to consistently peak at 82 – 85% egg production. This concept reinforces the statement made earlier regarding optimum body weight and optimum body condition of birds at start of lay. The fact that birds seem to do better when they are slightly heavy at maturity is likely a factor of such increased body mass acting as a source of additional energy in order to meet the bird's requirements at this time. It is undoubtedly true that any flock that does not gain some weight each week through peak production will give inferior egg production and hatchability.

Because energy intake is the major factor controlling egg production, then it is critical that feed intake be adjusted according to energy density of the diet (Table 6.19).

Table 6.19 Adjusting feed intake according to diet energy level at 22°C, g/bird/day

Daily energy need (kcal)	*Diet ME (kcal/kg)*				
	2600	***2700***	***2800***	***2900***	***3000***
300	115	111	107	103	100
320	123	119	114	110	107
340	130	126	121	117	113
360	138	133	129	124	120
380	146	141	136	131	127
400	153	148	143	138	133
420	162	156	150	145	140
440	169	163	157	152	147
460	177	170	164	159	153
480	185	178	171	166	160
500	192	185	179	172	166
520	200	193	186	179	172

Fig. 6.2 Egg Production of Broiler Breeder Hens From 25 to 60 Weeks of Age. *(From Lopez and Leeson, 1993)*

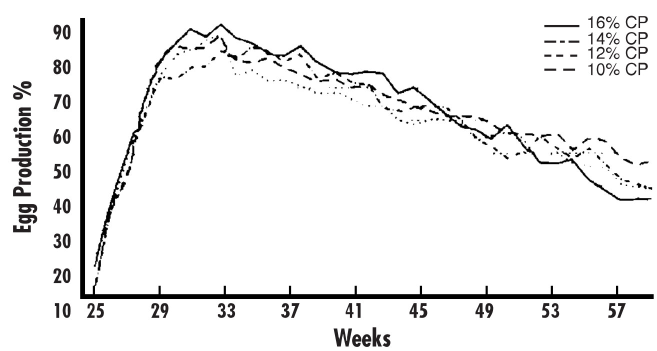
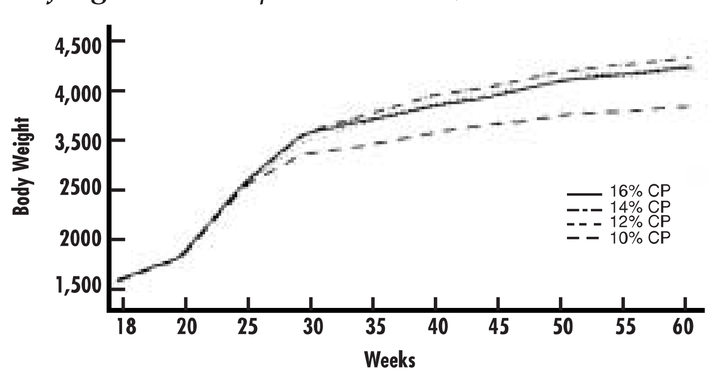


Fig. 6.3 Body Weight of Broiler Breeder Hens From 18 to 60 Weeks of Age. *(From Lopez and Leeson, 1993)*



Protein and amino acid needs of the breeder hen have not been clearly established. In general, most breeder flocks will be over-fed rather than under-fed crude protein because it is difficult to justify much more than 23 – 25 g protein per day. With a feed intake of 150 g daily, this means a protein need of only 15%. We have carried out studies involving very low protein diets where levels of methionine + cystine and lysine were kept constant (Figure 6.2). Diets were formulated at 0.82% lysine and 0.59% methionine + cystine in 10, 12, 14 or 16% CP diets. All diets contained the same level of energy and all other nutrients, and quantities fed daily were as suggested by the primary breeder. All roosters were separate fed a 12% CP male diet. Breeders fed 10% CP performed remarkably well, and although they did not have the highest peak, their better persistency meant no difference in overall egg production (Figure 6.2).

One of the most surprising results from the study, was better fertility with the lower protein diets. For example, overall fertility to 64 weeks for birds fed 10 vs. 16% CP was 95.4 vs. 90.6%. The reason for better fertility is thought to be due simply to the fact that these birds gained less weight (Figure 6.3), because there is a negative correlation between obesity and fertility.

These data suggests that protein/amino acid intake of the breeder hen is related to weight gain, and that excessive weight gain occurring after peak egg production is not merely a factor of energy balance. The results from this study were therefore somewhat unexpected, because birds fed the lowest level of protein produced the most chicks. Although we are not advocating 10% CP diets for breeder hens, these data shows that we could consider lower, rather than higher levels of protein, assuming that adequate amino acid balance is maintained.

6.5 Factors influencing feed and nutrient intake

a) Egg production

An egg contains around 100 kcal of gross energy, and so it takes some 120 kcal ME/d for egg synthesis. The yolk develops over a number of days, and so it is important to initiate feed increases prior to realizing actual production numbers. This concept is often referred to as lead feeding, and implies that the predetermined peak feed allowance will actually occur at some time prior to peak egg numbers. The suggestion is that peak feed be given at anywhere from 30 – 60% egg production. If flocks are very uniform in weight, it is possible to peak feed at 30 – 40%. However, with poorer uniformity (<80% @ ± 15%) then peak allowance should not be given until 60% egg production, or even later. Lead feeding programs are also influenced by management skills. Where there is good management with precise and even feed distribution, then peak feed can occur earlier.

The feed allowance for hens up to 26–28 weeks may need to be slightly higher than theoretical needs, since it is common for males to feed from the hen feeding lines. After 28 weeks, the head size of the males usually excludes them from the female feeder lines, and so after this time, feed allocation tends to be more precise.

High and sustained peak egg production can only be achieved with uniform breeder flocks fed to meet their nutritional requirements.

With 85 – 88% peaks now possible, it is obvious that we have to carefully plan and execute a feeding program tailored to meet the breeder's nutrient needs. Underfeeding results in peaks lasting only 3 – 4 weeks, and these are usually associated with the classical sign of loss or stall-out in body weight for 1 – 2 weeks. On the other hand overfeeding, especially with energy, will result in excessive weight gain, and while peak production may be little affected, there will be precipitous loss in egg production through 34 – 64 weeks of age. The basis of feed allocation at this critical time is obviously to allow genetic potential for increases in both egg numbers and egg size, and also to allow for modest weekly gains in body weight. Managers should consider 'challenge feeding' as part of their feed management system at this critical time.

Challenge feeding involves giving the hens extra feed on 2 or 3 days each week, based on need, without changing the base feed quantity scheduled for the flock. For example, a flock may receive 150 g/bird/day at peak, with an additional 'challenge' of 5 g/bird/day given three days each week. The challenge feed is therefore, equivalent to 3 x 5 g ÷ 7d = 2 g/bird/day. In reality birds receive the equivalent of 150 g + 2 g = 152 g/bird/day. The immediate question is why bother with this more complicated system, rather than just give the flock a base feed allowance of 152 g/bird/day? The advantages of challenge feeding, rather than simply increasing the base allocation are:

- on days of challenge feeding, feeding time will increase, and this helps to improve overall flock uniformity.

- it is easier to make adjustments to nutrient intake based on day-to-day change in needs as may occur with changes in environmental temperature.

- birds become accustomed to change in feed allocation, which will be important once feed withdrawal is practiced after peak.

- ease of tailoring nutrient needs to individual flocks. For example, a base feed allocation of 150 g /bird/day may be standardized across all flocks, with individual flock needs at peak being tailored with the quantity and/or frequency of challenge, depending on actual production, environmental temperature, etc.

The actual quantity and timing of challenge feeds must be flexible if they are to be used efficiently. In practice, the challenge should not represent more than 5% of total feed intake, and most often the quantity will be 1 – 3%. On the other hand, the quantity of the challenge should be large enough to meaningfully contribute to the factors listed previously. For this reason, there needs to be a balance between the quantity of feed given, and the frequency of this feeding. For example, a daily challenge of 2 g/bird/day will be much less effective than 5 g/bird/day given 3 times each week. In both instances birds are receiving 14-15 g/week as a challenge, but in the later example the challenge quantity is more meaningful and we are more likely to see a bird response in terms of egg output.

Challenge feeding should start when birds are at 60 – 70% production, and should be discontinued when egg production falls below 80%. For most flocks, therefore, we can expect to practice challenge feeding from about 29 through 40 weeks of age. The idea of challenge feeding is to more closely tailor feed allocation to breeder hen needs, and so there should be no standardized system. Managers must be given flexibility to alter challenge feeding based on fluctuating needs. In most instances, the challenge

will be used to lead birds into a sustained peak. Because the concept of challenge feeding is to more closely tailor feed allocation to needs, then it is usual practice to alter the quantity and/or duration of challenge as birds progress through peak egg production. Maximum challenge feeding should coincide with peak egg output, with lesser quantities given prior to, and after actual peak. On this basis we recommend challenge feeding to be reduced (but not discontinued) once birds are 2% below peak egg production. Following are three examples of challenge feeding tailored to three different flock situations (Tables 6.20 – 6.22).

In Table 6.20, because birds are uniform in both weight and maturity and a good quality diet is used, and there is no major temperature stress, the challenge is quite mild. For this flock, a heavier challenge may result in excess weight gain. This type of mild challenge is most frequently used where feed quality is ideal, and there is minimal disease and mycotoxin exposure.

In Table 6.21, there needs to be more challenge feed, because nighttime temperature is quite low and there is a problem with maturity related to poorer uniformity. On average, this flock may gain a little more weight than example birds in

Table 6.20 Breeders fed a high nutrient dense feed with good ingredient quality control. Expected high-low temperatures of 31°C – 24°C. Good flock uniformity at 20 weeks of age and previous flocks show consistent peaks of 85 – 87%

Egg production	*Base feed*	*Challenge feed*
35%	*150 g*	*None*
60%	*150 g*	*5 g/d, 2x/wk*
80%	*150 g*	*8 g/d, 2x/wk*
-2% from peak	*150 g*	*5 g/d, 2x wk*
79%	*150 g*	*None*
<79%	*Reduce*	*None*

Table 6.21 Breeders fed a high nutrient dense feed with good ingredient quality control. Expected high-low temperatures of 28°C – 14°C. Poor to average flock uniformity and previous flocks show variable peaks at 81 – 87%

Egg production	*Base feed*	*Challenge feed*
35%	*155 g*	*None*
60%	*155 g*	*6 g/d, 3x/wk*
80%	*155 g*	*8 g/d, 3x/wk*
-2% from peak	*155 g*	*6 g/d, 3x/wk*
79%	*155 g*	*None*
<79%	*Reduce*	*None*

Table 6.22 Low nutrient dense feed used with poor ingredient quality control, and so feed composition may be variable. Expected high-low temperatures, 28°C – 20°C. Average to good flock uniformity at 20 weeks of age, and past flocks show variable peaks at 80 – 86%

Egg production	*Base feed*	*Challenge feed*
40%	*165 g*	*None*
65%	*165 g*	*8 g/d, 3x/wk*
80%	*165 g*	*10 g/d, 3x/wk*
-2% from peak	*165 g*	*8 g/d, 3x/wk*
79%	*165 g*	*None*
<79%	*Reduce*	*None*

Table 6.20 and this will have to be accommodated with a more vigorous post-peak feed withdrawal program.

In Table 6.22, base feed allowance is increased because a low nutrient dense feed is used and challenge is fairly aggressive again due to concern over feed quality and poor uniformity. In the examples shown in Tables 6.20 – 6.22, it is assumed that managers will continue to maintain breeder body weight through peak, and make necessary adjustments to the challenge if over- or under-weight conditions are seen.

Challenge feeding can also be used post-peak if there are precipitous declines in egg production related to minor disease challenge or management or environmental stress. Under these conditions, challenges of 6 g/bird/day for two consecutive days are recommended. If no immediate response is seen in egg production, then the challenge should be discontinued. If egg production returns to normal, then the challenge should gradually be reduced over the next 2 – 3 days.

Challenge feeding allows tailoring of feed allocation to suit individual flock needs. Managers should be flexible in actual allocations, although maximum challenge feed allocation needs to coincide with peak egg production. Breeder hens will respond to a carefully planned challenge program, with sustained peak production and better post-peak persistency. On the other hand, the challenge should not usually represent more than 5% of total feed intake, because excessive challenge will invariably result in obesity and related loss in post-peak performance. In general, when birds are subjected to such stresses as variable feed quality, mycotoxin challenge and/or fluctuating or extreme environmental temperature, then a high base feed allowance, coupled with aggressive feed challenge, is recommended. On the other hand, lower feed inputs are possible where consistent quality high-energy feeds are used, and where there is good environmental control.

Once birds have peaked in egg production, it is necessary to reduce feed intake. There is often confusion and concern as to how much and how quickly feed should be removed, and this is somewhat surprising, since the same basic rules used pre-peak also apply at this time. This means that birds should be fed according to egg production, body weight and clean-up time. After peak production, feed clean-up time often starts to increase, and this is an indication of birds

being overfed. The main problem we are trying to prevent at this time is obesity. If feed is not withdrawn after peak, then because egg production is declining, proportionally more feed will be used for growth. After peak therefore, body weight becomes perhaps the most important parameter used in manipulating feed allocation. It is still important for birds to gain some weight, since loss of weight is indicative of too severe a reduction in feed allowance.

Feed allocation and withdrawal for breeder hens has to be based on needs. The hen needs nutrients for four major reasons, namely for growth, egg production, maintaining normal body functions and for daily activity. Each of these needs varies with the age of hen and environmental temperature, and also each need varies with respect to the type of nutrients utilized. Growth, egg production and maintenance all require protein and energy, while activity is only really demanding on energy needs. Actual estimates for these nutrient needs are shown in Table 6.23.

The maintenance need is perhaps surprisingly by far the largest single factor affecting energy requirements of the breeder. Secondly, it is egg production and lastly, growth and activity. In terms of protein needs, egg production and maintenance are the only two meaningful factors. However, as the bird gets older, the actual nutrient needs and the distribution of these needs change (Table 6.23). At 55, rather than 32 weeks of age, therefore, the bird needs less energy and protein for eggs, because egg production has declined (even though egg size has increased) but she needs more of these nutrients for maintenance because over the 23 week period the bird has grown and so needs more feed to maintain herself. At 55 weeks, if all goes well, we have significantly reduced growth rate, and so both protein and energy needs for growth are greatly reduced. The reduction in nutrient needs for lower egg production and less growth outweighs the needs for more maintenance, and the bottom line is overall reduction in daily need of the hen for both energy (460 vs 510 kcal) and protein (19 vs 21 g).

Reduced nutrient needs can be achieved by either simply reducing feed intake or maintaining feed intake constant but changing the energy and protein levels of the diet. In practice, reducing feed intake after peak production is by far the easiest and most foolproof method of reducing the bird's nutrient intake. Changing to a lower-energy, lower-protein diet means a change of formulation, which itself can be stressful to the bird. On multi-age farms, it is also more hazardous to have multiple diets being delivered to the farm which can get placed in the wrong feed tank.

The consequences of not reducing nutrient intake of the breeder hen after peak should be fairly obvious. The bird will not lay more eggs or become more active as a result of supplying more protein or energy than is required. Oversupply of these nutrients goes directly to increased growth which itself quickly causes increased maintenance requirement. This extra growth will be as fat, and muscle (protein) growth. Obesity quickly leads to reduced egg production, diverting even more nutrients into growth (fat). This vicious circle is often responsible for the very sudden drop in egg production seen with flocks that are overfed after peak egg production.

The final questions of course, are how much and how often do we reduce feed allocation after peak production? Regardless of how high a peak production is actually realized, we should not start to reduce feed while birds are at □ 80% production. The main reason for this is that peak egg

Table 6.23 Protein and energy requirements of breeder hens at 32 and 55 weeks of age at 24°C

	32 weeks of age		55 weeks of age	
Nutrient need	**Energy (kcal)**	**Protein (g)**	**Energy (kcal)**	**Protein (g)**
Growth	*40*	*1*	*5*	*None*
Egg production	*80*	*10*	*60*	*8*
Maintenance	*310*	*10*	*350*	*11*
Activity	*40*	*None*	*25*	*None*
Total	*470*	*21*	*440*	*19*

numbers do not usually coincide with peak nutrient needs for eggs because egg size is increasing through this period. In most flocks, peak nutrient needs for eggs (production x egg weight) will have been reached by the time birds have declined to 79 – 80% production, at about 39 – 40 weeks of age. At this stage of production, we can start to gradually reduce feed intake, and in general, the quantity of feed to be removed will depend on peak feed allowance. If birds were peaked on 165 g/bird/day then we likely need to remove more feed than for a flock peaked on 150 g/bird/day. Also, if temperature/seasonal changes are anticipated, then this should be factored into feed allocation. Impending warmer weather means we can take more feed away, while if cooler temperatures are anticipated, we may need to take very little feed away (because maintenance needs will naturally increase). Assuming that we have peaked a flock at 155 g/bird/day, and anticipate no major change in environmental temperature, then a feed reduction program, as shown in Table 6.24 is suggested.

With such a slow and steady removal in feed, it should be possible to prevent obesity in hens, while at the same time allowing adequate energy and protein for the inevitable slow decline in egg numbers. The reduction in feed intake is necessarily slow and involves small steps because as shown in Table 6.23, the actual nutrients going into eggs are quite a small proportion of the hen's total needs. Responding to a 5% decline in egg production, therefore, requires very small changes to the feed scale.

Some producers consider a 1 – 2 g/bird/day reduction in feed intake hardly worth bothering about, and either make no adjustment, or few much larger reductions. Sudden large reductions □ 4 g/bird/day can often be very stressful and result in sudden drops in egg production. Making no adjustments and continuing near peak allocation to 64 weeks, will be uneconomical in terms of birds becoming overweight with associated loss of egg production. In the example shown in Table 6.24, a bird fed according to this suggested schedule will eat about 22.8 kg to 65 weeks. Feeding 155 g through to 65 weeks, with no feed withdrawal, will result in an extra 1.5 kg feed intake. This quantity of extra feed will likely result in an additional 0.2 – 0.3 kg body weight gain, most of which will be fat.

Table 6.24 Feed allocation program for heavy breeders after peak production

Egg production (%)	*Approx. age (wks)*	*Daily feed intake (g/day)*
80	*39*	*155*
79	*40*	*154*
78	*41*	*154*
77	*42*	*152*
76	*43*	*151*
↓	↓	↓
74	*45*	*150*
↓	↓	↓
70	*50*	*148*
↓	↓	↓
65	*55*	*146*
↓	↓	↓
60	*60*	*144*
↓	↓	↓
55	*65*	*142*

b) Body weight

Maintenance represents the major need for energy and hence feed by the breeder and so knowledge of body weight is important in allocating feed. All too often, the monitoring of body weight stops when birds are transferred to the breeder house and so birds are fed solely according to egg production. The importance of body weight and body reserves of breeders through peak production has already been emphasized and this means continual monitoring of body weight. It is essential that birds continually gain some weight through peak production. Loss of weight or stall-out in weight usually implies that birds are not getting enough nutrients, and that loss in egg production will occur within 7 – 10 d. In this context, monitoring of body weight will give an earlier indication of impending problems. From 20 – 32 weeks of age, pullets should ideally be weighed weekly.

Feeding to body weight assumes that birds are at ideal weight around 22 weeks of age (□2.2 kg). If birds are over or underweight, then adjustments to intake must be made. If birds are under weight, then they should obviously be given more feed than the standard recommended allowance in an attempt to stimulate growth. Overweight birds should also be given more feed (Table 6.25). This apparent dichotomy of ideas is based on the fact that heavier birds have a larger maintenance requirement and so need more feed to meet their overall energy (nutrient) requirement. This is a difficult concept for farm managers to accept since they are afraid of over weight birds getting even heavier. There is obviously a fine line between over feeding and feeding to requirement for this overweight bird, but as previously discussed, the ideal 20 week-old pullet is slightly overweight in comparison to most primary breeder guidelines. Under ideal conditions, pullets will not lose weight after 20 weeks of age, rather they show continued small increments of weight gain each week and hopefully are around 3.5 kg at the end of their laying cycle.

Table 6.25 Example of energy allowance for breeders (kcal ME/day)

Age (wks)	*Underweight*	*Ideal Weight*	*Overweight*
18	230	240	250
20	270	250	280
22	310	295	325
24	345	345	380
26	430	430	470

c) Feed clean-up time

Feed clean-up time should be used as an indication of adequacy of feed allocation. Major changes in clean-up time are an indication of over- or under-feeding and as such, are an early warning of subsequent changes in body weight and egg production. As a routine management procedure, the time taken to clean-up most of the feed allocation should be recorded each day to the nearest 30 minutes. If clean-up time varies by more than 60 minutes on a daily basis, then bird weight should be measured immediately. However, major changes in feed allocation should not be made solely on the basis of feed clean-up time, rather these values should be used as a guide to investigate feed needs through more precise monitoring parameters. Feed clean-up time with high-yield strains of breeder hens is often greater (+ 1 hr) compared to the more traditional strains and merely reflects a less aggressive feeding behaviour.

Clean-up time for feed can vary considerably from flock to flock for no apparent reason. For example, one flock may take 4 hours to clean-up feed, whereas a sister flock of the same age etc. can take 2 hours. For this reason absolute time taken to clean-up feed cannot be used as a management guide – the only useful parameter is change in clean-up time. Sudden changes in clean-up time often precede changes in body weight by 2 – 3 d, and changes in egg production by 10 – 12 d.

d) Morning vs. afternoon feeding

Choice of feeding time of adult breeders can influence the production of settable eggs, eggshell quality, fertility and hatch of fertiles. In most instances, these factors are a consequence of feeding activity displacing other important daily routines, such as nesting and mating. Breeder hens consume their feed in 2 – 6 hours each day. This large variation in feed clean-up time relates to diet energy level, feed texture and perhaps most importantly, environmental temperature. In hot climates breeders often take much longer to eat feed, and this is especially true of high-yield strains. Most managers consider this extended feeding time to be advantageous, because it ensures more even allocation of feed across the flock where even the most timid birds have time to eat.

If breeders are fed early in the morning, then the most intense feeding activity will be over by 9 a.m. Again, this is ideal in terms of reducing heat load in the early afternoon period. This timing is also ideal in terms of differentiating the main feeding time from nesting activity.

Depending upon when lights are switched on in the morning, most eggs are laid in the 9 a.m. – 12 noon period. Feeding at say 8 a.m., would therefore, induce birds to feed at a time when they are usually in the nests. In fact, eggs dropped in the area of the feeder are a very good indication of late-morning feeding. Obviously some of these eggs will get broken or become too dirty for setting.

A few years ago there was interest in feeding breeders in the late afternoon. The main advantage is claimed to be an improvement in eggshell

thickness, and in fact in many field trials this is found to be true. Improved shell thickness is likely a consequence of the bird eating calcium at a time when shell calcification is starting (for the next day's egg) and also the bird having more feed with calcium in its crop when lights are switched off. If eggshell quality is a problem, then afternoon feeding seems a viable option. Alternatively, birds could be given a 'scratch' feed of large particle limestone or oystershell in the late afternoon.

However late afternoon feeding has a number of potential disadvantages. Firstly, there is increase in shell thickness. This should not be a problem as long as incubation setter conditions are adjusted so as to maintain normal moisture loss. In most situations this means reduction in setter humidity to accomodate less moisture loss through a thicker shell.

A greater concern with later afternoon feeding is potential loss of mating activity, and increase in incidence of body-checked eggs. Mating activity is usually greatest in late afternoon. If hens are more interested in feeding at this time, then there can be reduced mating activity and also more aggression between males. Body-checked eggs are characterized by a distinct band of thickened shell around the middle of the egg (sometimes called belted eggs). This defect is caused by the eggshell breaking during its early manufacture in the bird's uterus. The bird repairs the crack, but does so imperfectly. Such eggs have reduced gas and moisture-transfer characteristics and usually fail to hatch. The most common cause of body-checked eggs is sudden activity, movement, stress, etc. on the bird. This extra activity takes place when feed is given in late afternoon, and so there will likely be fewer settable eggs produced.

e) Environmental temperature

Environmental temperature is the major on-farm factor influencing feed intake and energy needs. Table 6.26 indicates partitioning of energy requirements at various environmental temperatures.

Table 6.26 Peak feed needs of breeder hens at various environmental temperatures (g)

Feed need	*18ºC*	*24ºC*	*34ºC*
Growth	*10*	*10*	*10*
Maintenance	*140*	*125*	*110 (130)*
Eggs	*30*	*30*	*30*
TOTAL	***180***	***165***	***150 (170)***

As temperature increases, so feed need is reduced. In this example, two values are shown for maintenance feed need at 34ºC. The value in brackets (130 g) represents feed need when the bird is under stress and panting etc., where she needs energy to drive the cooling mechanisms in the body. In this situation, total feed need becomes 170 g, which is actually greater than suggested at 24ºC. It is often difficult to get breeders to eat more feed under heat stress conditions, yet this increased energy intake is critical if egg production is to be maintained. Table 6.27 shows model predicted energy needs of breeders maintained at temperatures of from 14ºC to 35ºC.

Depending upon acclimatization, birds will die when temperatures reach 40ºC, while few birds can survive for very long at temperatures below –10ºC. At –2ºC, the comb and wattles will freeze. In most commercial houses today there is concern with bird comfort in the range of 0ºC

to 38ºC depending upon the degree of environmental control. Breeder performance will be optimized at around 22 – 24ºC and apart from changes in egg production, there is an incentive in optimizing feed efficiency by maintaining this ideal temperature. While most discussion on environmental control of breeders focuses on temperature, it must be remembered that the prevailing relative humidity is often the factor causing distress to the bird. Conditions of high temperature and low humidity (e.g. 32ºC, 40% RH) are quite well tolerated by the bird, while high temperature and high humidity (e.g. 32ºC, 90% RH) are problematic.

In discussion of the effect of environmental temperature on breeder performance, there is some debate about how temperature is actually defined. Measuring house temperature at first glance seems to be a straightforward task. Thermometers or temperature probes can be positioned at bird height and records collected daily. However, there is usually considerable fluctuation in temperature throughout the day. For example breeders can be subjected to a daytime high of 26ºC and a nighttime low of just 8ºC. How do we reconcile this temperature fluctuation in trying to calculate maintenance energy and feed needs of the breeder? The traditional approach has been to simply take an average of all readings or the average of the high and low daily temperatures e.g. (26º + 8º)/2 = 17ºC. However breeders do not behave in a similar manner during the day compared with nighttime darkness. During the day, most breeders are rarely in contact with other birds and so the air around them is at a temperature very similar to that recorded on the thermometer.

When lights are switched off however, birds invariably sit down, and are usually huddled close to their flockmates. Sitting, rather than standing, will reduce heat loss of the bird, while huddling as a group has a great insulating effect. This behavioural change in the bird has the effect of lessening the impact of the cooler night temperature. Simply averaging high and low temperatures, in order to calculate feed need, may therefore be inaccurate. We therefore need a system that reduces the relative significance of the night temperatures, and so propose the following solution:

Table 6.27 Model predicted energy needs of breeder hens as affected by environmental temperature (kcal/day)

Age (wks)	*B. wt (g)*	*Egg mass (g/d)*	*Temperature*				
			14ºC	*18ºC*	*24ºC*	*29ºC*	*35ºC*
22	2320	-	284	256	229	201	175
24	2450	3.5	300	272	254	215	187
26	2565	18.0	350	320	290	260	235
28	2665	44.3	439	409	379	348	320
30	2758	53.7	475	444	413	382	352
40	3100	53.6	490	456	423	390	357
50	3310	48.0	482	445	411	376	341
60	3425	41.0	464	428	393	357	322
70	3500	34.0	445	410	373	337	302

Adapted from Waldroup et al. 1976

Effective temperature =[(daytime high temperature x 2) + (nighttime low temperature)]/3

For the above example, the calculation becomes:

$$[(26 \times 2) + 8]/3 = 20°C$$

The 'effective' temperature becomes 20ºC rather than 17ºC as calculated by the traditional method. The nighttime low of 8ºC is given less emphasis because birds get an insulative effect from sitting and huddling. These birds therefore need less 'extra' heat in order to keep warm than is predicted from simple thermometer measurements. Table 6.28 shows calculations using this same formula, at various day and night temperatures. If we assume that 26ºC is an ideal temperature for breeders then we can calculate the extra feed needed for maintenance as effective temperature declines. If a diet provides 2850 kcal ME/kg, a 3 kg breeder will need an extra 1.5 g feed for each 1ºC decline in effective house temperature. Table 6.28 shows such calculated extra feed needed by breeders kept at various day and night conditions relative to breeders kept in an ideal environment of constant 26ºC.

The deleterious influence of a cold night temperature is therefore not as significant as a comparable cold temperature during daytime. With a daytime temperature of 24ºC as an example, we only have to feed an extra 12 g daily in order to counteract a chilly night temperature of 6ºC. Failure to make such an adjustment long term will mean that the hen will either lose weight and/or reduce egg output in an attempt to conserve energy.

Another question often asked is how often should feed intake be adjusted in order to accommodate fluctuating environmental temperatures? Weather predictions can be notoriously inaccurate, and so day-to-day adjustments seem unwise, as well as being impractical for the farm staff. The bird does have a quickly usable store of energy

Table 6.28 Effect of temperature on increased feed allowance relative to 26ºC standard (gram/hen/day)[1]

Daytime temperature (ºC)	*Nighttime temperature (ºC)*														
	26	**24**	**22**	**20**	**18**	**16**	**14**	**12**	**10**	**8**	**6**	**4**	**2**	**0**	**-2**
26	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
24			4	5	6	7	8	9	10	11	12	13	14	15	16
22				7	8	9	10	11	12	13	14	15	16	17	18
20					10	11	12	13	14	15	16	17	18	19	20
18						13	14	15	16	17	18	19	20	21	22
16							16	17	18	19	20	21	22	23	24
14								19	20	21	22	23	24	25	26
12									22	23	24	25	26	27	28
10										25	26	27	28	29	30
8											28	29	30	31	32
6												30	31	32	33

[1]*Feed @ 2850 kcal ME/kg*

in the form of body fat, and so, in the short term, it can use this as a supplement to feed if environmental temperature declines on a daily basis. However, there are limits to the bird's ability to mobilize large quantities of body fat over a prolonged period of time, the consequence of which is usually loss in egg production. Such loss in egg output may simply be a response related to energy conservation, although it may also be a consequence of change in hormone balance of the bird. The latter effect is likely to have more serious long-term consequences to egg production. As a generalization, it is estimated that the bird can use its body fat reserves to accommodate the equivalent of a 6º – 8ºC drop in temperature over 4 – 5 consecutive days. Decreases in house temperature that are greater than this, or that occur for a longer period of time should be accommodated by appropriate increases in feed allowance. Feed changes in response to cooler temperatures should therefore be accommodated at least on a weekly basis.

Heat distress is a major challenge for breeder managers. It is usually unwise to change diet specifications in response to short-term changes (4 – 7 d) in the environment, yet 'summer' diets are advantageous in many regions. Diets for hot weather conditions are usually higher in energy (2950 kcal ME/kg minimum) and contain minimal crude protein (<15.5%) with normal levels of essential amino acids. There are advantages to using at least 4% added fat together with 250 mg/kg of vitamin C. Water intake should be encouraged, by adjusting diet salt levels to a maximum commensurate with maintaining litter quality and egg cleanliness. Table 6.29 indicates water balance of breeders at 22 vs. 35ºC where there is almost a doubling of water intake, due to increased evaporative losses.

Table 6.29 Water balance in breeders at 22 vs. 35ºC (ml)

	22ºC	35ºC
Water intake	300	500
Excreta loss	120	200
Egg water	55	55
Respiratory loss	125	245

Birds do not sweat and so this important cooling mechanism is unavailable to them. As an alternative, birds lose heat by evaporation through panting and loss of moisture in respired air. Evaporation is a very efficient means of heat-loss. For each 1 g of water vaporized, about 600 calories of energy are utilized. Much above 28ºC, evaporation becomes the most important route of heat loss for the bird. Unfortunately many conditions of heat stress also involve high humidity, and this situation adds increased difficulties on the bird for dissipating heat. A practical solution is to disrupt the boundary layer of air immediately surrounding the bird, with increased air movement through mechanical systems such as circulating fans. Table 6.30 indicates the cooling effect of increased air speed for breeders maintained at 29ºC.

Another system used for reducing the heat load is evaporative cooling. If air is passed over a fine stream of water, then it heats and evaporates some of the water, which takes substantial quantities of heat from the air. The system obviously works best in conditions of moderate humidity because the air must pick up moisture, and so at the extreme of 100% humidity in outside air, evaporative cooling is not very effective. With incoming air at 20% RH, a 15º – 20ºC reduction in temperature by evaporative cooling is theoretically possible. At more normal levels of 60

– 70% RH, an 8º – 10ºC cooling effect is possible, while at > 75% RH, the cooling potential is about 5ºC. Each 1ºC of cooling is associated with about a 5% increase in RH.

Table 6.30 Cooling effect of air movement for breeders at 29°C

Air speed (meters/min)	*Cooling effect (ºC)*
15	0.5
30	1.0
45	2.0
60	3.0
75	4.0
90	5.0
105	6.0

f) Eggshell quality

As egg output increases, especially from 28 – 38 weeks of age, there is added pressure on shell synthesis. Consequently, maintenance of shell quality is an emerging issue in breeder nutrition. Poor shell quality means potential loss of settable eggs and reduced hatch of fertiles due to change in moisture loss from the thinner shelled eggs. Nutritionally, the major nutrients of concern are calcium, available phosphorus, and vitamin D_3. There may be an advantage to phase feeding both calcium and phosphorus, and providing extra vitamin D_3 as a water supplement. Calcium level can be increased over time by adding an extra 5 kg/tonne limestone to the diet at 45 and 55 weeks of age. At the same time available phosphorus levels can be reduced by at least 0.05%. If shell quality is problematic, breeders sometimes respond to vitamin D_3 given in the drinking water – 300 IU/bird twice per week is recommended. While feed is usually the only source of calcium and phosphorus considered in meeting the breeder's needs, it is known that birds eat litter which contains these nutrients. Such litter eating has been suggested as the reason for improved shell quality of floor vs. caged birds under experimental conditions. Controlled studies have shown that breeders eating 20 g litter/day, consume an extra 7% calcium and 12% available phosphorus. Unfortunately shell quality is influenced not only by levels of calcium in the diet, but also feeding time and also particle size.

Most of the shell material is formed in the daily period of darkness, when the hen is not eating. During this time of rapid shell accretion, the bird relies on the stores of medullary bone for almost 50% of the calcium used to make a shell. Between successive calcifications, this bone must be replenished, in the form of calcium phosphate. One reason for decline in shell quality over time is gradual loss in efficiency of this deposition and withdrawal of medullary bone. Although the medullary bone reserve is essential to shell formation regardless of diet, its role is somewhat reduced if the bird has some calcium being absorbed from the digestive tract at night. This situation leads to the idea of afternoon feeding of calcium, to provide a calcium source in the digestive tract that can slowly be released at night, and so aid shell formation. At the end of the day, the breeder will ideally have a few grams of calcium in the digestive tract, that can slowly be digested and absorbed, and then directed to the shell gland. Farmer *et al.* (1983) determined the quantity of calcium remaining in various regions of the digestive tract following a 7 a.m. feeding of a diet providing 4.27 g calcium/day (Table 6.31).

Table 6.31 Calcium remaining in various regions of the digestive tract following 7 a.m. feeding of a diet providing 4.27 g calcium/day (g)

Time	*Crop*	*Gizzard*	*Small intestine*	
			Upper	*Lower*
11 a.m.	*1.64*	*0.53*	*0.22*	*0.32*
7 p.m.	*1.36*	*0.11*	*0.07*	*0.14*
11 p.m.	*0.86*	*0.21*	*0.03*	*0.07*
3 a.m.	*0.24*	*0.20*	*0.09*	*0.09*
7 a.m.	*0.01*	*0.18*	*0.09*	*0.17*

Adapted from Farmer et al. (1983)

With lights out at 11 p.m. the breeders had little calcium remaining in the digestive tract overnight. Time of feeding calcium, therefore, seems important. Because most breeders are fed early in the morning and with clean up time of only 2 – 3 hours, then there is little potential for calcium reserves remaining in the gut in the evening. When breeders are given experimental diets containing just 0.4% calcium, they are found to be able to maintain shell quality only when an extra 3 g calcium is force fed at around 4 p.m. Such force feeding at 8 a.m. resulted in very poor shell quality.

Feeding calcium in the late afternoon therefore seems ideal if shell quality is problematic. This can best be done by simply broadcasting oystershell or large particle limestone directly onto the litter at around 4 p.m. The feeding activity associated with this technique also helps in bringing hens down from the slats, onto the litter, which usually means greater mating activity at this time. This technique raises another concern about calcium source, namely particle size. Usually, the larger the particle size, the slower the rate of digestion, and so the more prolonged the metering out of calcium for shell formation. The reason for poor shell quality following force feeding 3 g of calcium at 8 a.m., as described previously, relates to the fact that the bird cannot utilize this sudden influx of calcium, and has no reserve other than the medullary bone. Large particle limestone and oystershell are usually digested more slowly, and this is the reason suggested for better shell quality with these products. Ideally a mixture of fine and coarse particles should be used because this gives both rapid and slow metering of calcium for metabolic needs. The disadvantage of both oystershell and large particle limestone is that they are very abrasive to mechanical equipment. Table 6.32 summarizes diet specifications aimed to optimizing shell quality.

Table 6.32 Diet specification aimed at optimizing shell quality

	Breeder age		
	25 wks	45 wks	55 wks
Calcium (%)	3.1	3.3	3.5
Available phosphorus (%)	0.40	0.36	0.32
Crude protein (%)	15.5	14.5	14.0
Methionine (%)	0.35	0.32	0.30
Water supplement			
Vitamin D_3		- 300 IU/bird/2 consecutive days per week	
Vitamin C		- 20 mg/bird/2 consecutive days per week	

6.6 Breeder male feeding programs

Male condition is obviously critical for optimum yield of fertile eggs. If a breeder hen produces an egg, then infertility is usually due to simple absence of sperm in the oviduct, and this in itself is directly related to mating frequency and/or mating success. In many situations, therefore, loss of fertility is caused by incorrect body condition of hens and/or roosters, such that mating activity is reduced. For hens, this is usually due to overfeeding and obesity, and in roosters is caused by both over- and under-feeding. Just as great care is taken to meet the hen's nutrient requirements with continual adjustments to diet or feed allocation, so we have to carefully monitor the male's condition and environment and to feed accordingly. In many respects, it is easy to predict the male's nutrient requirements, because we do not have the complication of egg production as occurs with the hen. The feeding program therefore has to meet just two basic needs namely, growth and maintenance of body functions. The major criteria of our male feeding programs, therefore, are monitoring body weight and body condition and controlling frame size and uniformity.

The period during early maturity is probably the most critical in the adult life of the breeder male. Up to about 30 weeks of age, the breeder male is still expected to grow quite fast. For example a weight gain of around 1.4 kg is expected between 10 and 20 weeks of age, and this is only slightly reduced to around 1.2 kg weight gain between 20 and 30 weeks. It is therefore, very important to maintain this growth potential through to 30 weeks, and so continued monitoring of body weight is critical.

The major complication of feeding the breeder male at this time relates to the separate male-female feeding systems now commonly used. Grills on the female feeders are usually around 43 mm in width. Unfortunately 19 – 21 week old male breeders, when first moved to the breeder facilities, will have head width slightly less than this. The males will therefore, eat from the female feeders while they still have smaller head size. Individual males will grow at different rates, and their head width will reach > 43 mm, on average around 26 – 28 weeks. The larger birds usually have larger heads, and

so there is a self-limiting system that evolves with exclusion over time of males from the female lines. However, we are faced with the problem of trying to estimate the males' feed and nutrient intake. One answer to this problem has been the use of so-called 'nose-bars' which are plastic rods inserted through the nostrils of the bird. This 'nose-bar' effectively excludes the male from the female line almost immediately, and so males will only take feed from their own feed line. The effectiveness of nose-bars has been reported as quite variable, and like many situations with broiler breeders, there undoubtedly needs to be a desire by the flock supervisors to make the system work. Another potential solution to the problem of male access to the hen feeders, is to delay placement of the males in the breeder house until 22 – 23 weeks, when the male's head width will naturally be wider. This management decision should not affect fertility, because eggs are rarely saved for hatching until 27 – 28 weeks of age, and by this time there will be normal male activity in the breeder house. If males are held in the growing facilities until 22 – 23 weeks, it is important to still light stimulate them according to the hen lighting schedule. This will ensure that roosters are as mature as the hens when introduced at this later date.

Leaving males un-dubbed also helps in earlier exclusion of males from the female line. Sometimes this causes problems of roosters getting their combs caught in mechanical equipment, and here just dubbing the back 20% of the comb seems beneficial, without really affecting the 'size' of the comb. Consideration of comb size raises another important consideration of feeder design. Much emphasis has been placed on grill width (□ 43 mm) although too often grills provide too much height, such that roosters will force their way into the hen feeders. If roosters are not dubbed, then grill height should be no more than 70 mm, and ideally closer to 65 mm. If roosters are dubbed, then grill height should be no more than 60 mm.

The other major variable affecting breeder male feed intake, is environmental temperature. Because maintenance plays such a major role in nutrient needs, environmental temperature can greatly influence the amount of energy needed to maintain body temperature. Birds will need more energy in cooler environments, and less energy under warmer conditions. Unfortunately, it is difficult to differentiate energy from the other nutrients in a diet, and so meeting fluctuating energy needs can only be accommodated (practically) by varying overall feed intake.

Table 6.33 gives examples of feed intake for breeder males, with emphasis on the critical period up to 36 weeks of age. Because in most cases males will have some access to the female feeders, we have emphasized this system in Table 6.33 and shown suggested intakes under various environmental conditions. Table 6.33 also shows suggested feed intake for males excluded from female feeders, using techniques such as nose bars. Under comparable environmental conditions, these birds should be given more feed, because this allocation is their only source of feed.

When roosters have access to hen feeders, we have a major feeding management decision to make at around 28 – 30 weeks of age. At this time, almost all roosters will be unable to get into the hen feeder, and so they are suddenly faced with a potential major reduction in feed intake. At this time, the roosters can start to lose weight and/or start to become very aggressive. One management decision, as shown in Table 6.33, is to increase the rooster feed at this time, and then more gradually wean them off of this extra allowance over the next few weeks. Roosters that previously had access to the hen feeder line are given more feed, especially from 30 – 36 weeks, compared to those

Table 6.33 Examples of feeding schedules for male breeders consuming a diet of around 2900 kcal ME/kg (grams/bird/day)

	Assuming males have access to hen feeders until approximately 28 weeks of age			
Age (wks)	*> 35ºC*	*20 – 28ºC*	*kcal ME/day*[2]	*< 15ºC*
20	108	110 (115)[1]	319	120
22	110	115 (118)	334	125
24	112	118 (120)	342	130
26	120	125 (130)	363	135
28	124	130 (135)	377	140
30	130	135 (135)	392	150
32	135	140 (130)	406	155
34	130	135 (130)	392	152
36	125	130 (128)	377	148
40	125	128 (128)	370	145
50	120	126 (126)	365	140
60	120	126 (126)	365	140

[1]( ) *assuming males totally excluded from hen feeders*

[2] *20 - 28°C*

birds with nose-bars etc. By 40 weeks of age, all roosters should be fed about the same amount of feed, regardless of whether or not they previously had access to the hen feeders.

After 36 weeks of age, obesity is an ever-present problem with male birds. The critical nutrients at this time are again energy and protein/amino acids. After 35 weeks of age, the rooster needs only the equivalent of around 10% crude protein, albeit well balanced in important amino acids. Energy needs are shown in Table 6.33 although sample weighing of birds will quickly tell if the allocation is correct. If roosters become excessively overweight/obese there should be an attempt at reducing their nutrient intake. If roosters are 200 – 400 g overweight, then body weight control can be achieved by reducing daily feed allowance by 5 g/bird/day each week until desired weight and condition are achieved. If roosters are >500 g overweight, it may be essential to use a low-nutrient dense feed (see next section) as well as reducing allocation over time. The reason for using a low-nutrient dense feed is to maintain weight uniformity because proportionally more feed can be given daily (albeit at reducing quantities weekly). Any manager facing these problems should seriously evaluate the feeding management strategy of birds in the critical 19 – 30 week period.

Male and female breeders will usually be fed the same diets up to maturity. In the breeder facilities, there is the choice of using the breeder hen diet for all birds, or a separate diet specifically formulated for males. Such male diets will usually be much lower in crude protein, amino acids and calcium compared to the breeder hen diet. The advantage of a separate male diet is that it more closely meets the male's nutrient requirements and allows for a slightly more generous feeding allowance. The protein and amino acid needs of the mature male are very low, being in the range of 10% CP. Such low pro-

tein diets are often difficult and expensive to formulate, but body weight control, and subsequent fertility, will usually be improved. A practical compromise formulation is around 12% crude protein or to use a 14 – 15% pullet grower diet. When low protein diets are used, it must be remembered that protein quality is still very important. For these low protein diets, methionine should be maintained at 2% of the protein, and lysine at around 5% of protein. Using a lower energy level, such as 2650 kcalME/kg, together with the lower protein, means that we can give males more feed, which will prolong feeding time and help maintain body weight uniformity. The calcium present in the hen breeder diet is also excessively high for the male. Because it is not producing eggshells, the male needs only 0.7 – 0.8% calcium in the diet. This extra calcium intake may pose additional stress on the kidney, although under most farm conditions, the roosters can handle this extra calcium load. However, when combined with other stressors to the kidney, such as high protein, or high mineral intakes, or mycotoxins such as ochratoxin, there can be problems with the general metabolism of the bird's kidney. An example of a male diet is shown in Table 6.34.

Table 6.34 Male breeder diet specifications

Metabolizable energy (kcal/kg)	*2650 - 2750*
Crude protein (%)	*10.0 – 12.0*
Calcium (%)	*0.75*
Available Phosphorus (%)	*0.30*
Sodium (%)	*0.18*
Methionine (%)	*0.28*
Methionine + Cystine (%)	*0.44*
Lysine (%)	*0.55*
Tryptophan (%)	*0.13*
Mineral-Vitamin Premix	*As per breeder hens*

6.7 Feed efficiency by breeders

Most producers in the poultry meat business could give a close approximation of feed efficiency in broilers, but few managers or technicians have comparable values at their fingertips for breeder performance. To some extent this is a fault of breeding companies because virtually no management guides contain this important information.

Table 6.35 shows the feed efficiency data for breeders calculated in terms of feed or nutrients per hatching egg or per chick. Data is shown to 64 weeks of age, which is the most common age for flock depletion. Values are also shown for breeder hens alone or hens with 8% males. For hens alone to 64 weeks of age, feed usage is calculated at 300 g during the breeder phase or 370 g including both grower and breeder phases, for each chick produced. Comparable numbers per hatching egg are 260 and 320 g. There is considerable variation in the level of dietary energy fed to breeders worldwide, and so perhaps a more accurate assessment of feed efficiency, for comparative purposes, is feed energy usage per egg or per chick. To 64 weeks of age, total energy intake, including the carrying cost of

Table 6.35 Feed efficiency of breeders

	Females only		*Females + 8% males*	
	0 – 64 wks	*24 – 64 wks*	*0 – 64 wks*	*24 – 64 wks*
Per hatching egg:				
Feed (g)	320	260	345	280
Energy (kcal)	915	750	980	800
Protein (g)	50	40	53	43
Per chick:				
Feed (g)	370	300	400	320
Energy (kcal)	1050	860	1130	920
Protein (g)	60	50	62	50

the males is 980 and 1130 kcal ME per hatching egg and chick respectively. As a simple rule of thumb therefore, we expect an energy cost of about 1000 kcal ME per hatching egg or chick. Because there are two values used in calculation of any measure of efficiency, the bottom line can be improved by maximizing one value and/or minimizing the other. This means that in theory, efficiency can be improved by increasing egg and chick output and/or by reducing feed intake. Unfortunately these two factors cannot be changed that easily. It is difficult to increase egg output *per se* because hopefully this is already being maximized with the standard on-farm management practices. Likewise, we cannot simply reduce feed intake by an arbitrary amount without expecting some loss in performance. However, there may be some potential for fine-tuning these parameters.

6.8 Nutrition and hatchability

Successful hatching of an egg depends upon a fertile egg having adequate nutrients and environmental conditions, such that the embryo can develop into a viable chick. From a nutritional point-of-view, hatchability can be influenced by fertility of both male and female breeders, the nutrients deposited in the egg for the embryo, and certain physical egg characteristics that can affect gas and water exchange during incubation. Traditionally, vitamin status of breeders is often considered the major nutritional factor influencing hatchability, although we now know that imbalance or excess of a number of nutrients can affect embryo viability. In the following discussion, it is assumed that incubation conditions are ideal, and also that eggs are stored and transported under ideal environmental and sanitary conditions.

a) Fertility

There is surprisingly little information available on the effect of nutrition on fertility, and especially for the hen. With hens it is assumed that if a bird is capable of producing eggs, and if viable sperm are available, fertility will occur. Nutritional effects on female fertility are, therefore, assumed to be quite minor in relation to nutritional effects on egg formation *per se*. While this is true for nutrients such as vitamins and minerals, it may not be true for nutrients affecting general body size and body composition, such as diet protein and diet energy. Protein level of the diet of breeder hens can have a significant effect on fertility (Table 6.36).

Table 6.36 Diet protein and female fertility to 64 weeks of age

Diet protein (%)	*Fertility (%)*
16	91.6[b]
14	93.3[a]
12	95.1[a]
10	95.4[a]

In these diets, methionine and lysine levels were kept constant, as was energy level, and only diet crude protein was varied. All roosters were fed a separate male diet at 12% CP, and so the data shown in Table 6.36 is a true female effect. Lopez and Leeson (1995) concluded that this apparent crude protein effect was simply due to body weight, because hens on the lower protein diets were smaller throughout the experiment. Birds fed 10% CP were some 500 g smaller than birds fed 16% CP at 64 weeks, even though feed and energy intakes were similar for all treatment groups. Limiting excess body weight after peak production is, therefore, important in maintaining greater mating activity of these smaller more active birds. In this respect, overfeeding both protein and energy is expected to reduce fertility, simply by making birds obese, and so less willing to mate with the roosters.

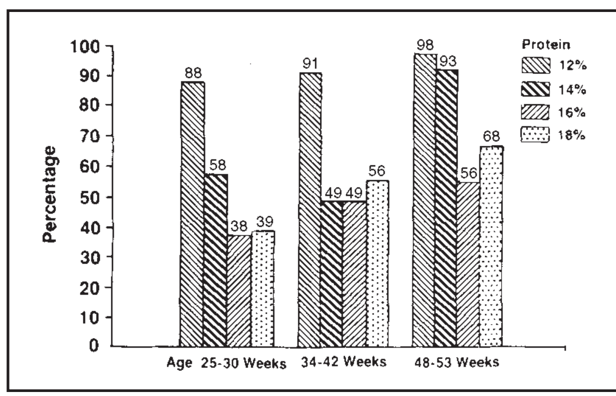
Table 6.37 Adult male performance in relation to energy intake

	Males producing semen (%)			*Hatch of set*	*Sperm penetration day 2*	*Testes wt.*
kcal ME/d	***38 wk***	***42 wk***	***46 wk***	*(%)*	*(#)*	*(g)*
290	100	55	36	61	20	9
330	100	73	64	66	100	12
370	100	100	82	65	160	26

Adapted from Bramwell et al. (1996)

This same concept also applies to roosters, where overfeeding of protein and/or energy is likely to result in reduced fertility. Overfeeding of male Leghorn breeders results in a dramatic decline in total sperm production with associated increase in production of dead spermatozoa. The introduction of separate male feeding systems has also resulted in better fertility, simply because of better control over feed intake of the rooster. However, even with separate male feeding, it seems advantageous to use low protein diets (McDaniel, 1986, Figure 6.4).

Fig. 6.4 Diet protein level and percentage of roosters producing semen (from McDaniel, 1986).



Feeding inadequate amounts of energy also has a deleterious effect on semen production by older males (Table 6.37).

b) Hatchability

Nutritional effects on hatchability of fertile eggs are not easily quantified, apart from the effect of gross deficiencies of vitamins and some other nutrients. Table 6.38 provides a summary of common embryo deficiency symptoms for selected vitamins and minerals. It should be emphasized that classical deficiency symptoms of individual vitamins are rarely seen. More often, multiple vitamin deficiencies occur when vitamin premixes are inadvertently omitted from the diet, or more commonly, deficiencies are induced by some other nutrient or toxin. These latter effects are obviously difficult to diagnose, since diet analysis reveals a correct vitamin level, even though a deficiency of that vitamin is evident.

In situations of complex vitamin deficiency, caused for example by accidentally failing to add the vitamin premix, then riboflavin deficiency is often the first to appear. This has the most dramatic effect on breeders, with hatchability reaching very low levels in 3 – 4 weeks (Table 6.39).

In this study hens were fed corn-soy diets where the premix was formulated without individual vitamins as detailed. For some vitamins, therefore, corn and soybean meal will provide some base level of vitamins and this may be the reason for differential results within the diets. As already indicated, the response to riboflavin is most severe, with hatchability down to zero in seven weeks. After 15 weeks of deficient diets, we reintroduced a regular fortified diet, and as shown in Table 6.39, for all treatments hatchability returned to normal within 4 weeks. Hatchability problems related to vitamin deficiencies therefore seem reversible once adequate diets are fed, and there seems to be no longlasting effect.

A practical problem with on-farm nutritional deficiencies is that hatchability declines are not seen until three weeks after deficient diets are consumed. For this reason, weekly checks on embryo survival will give a much quicker indication of potential problems. There is an excellent correlation between feeding vitamin deficient diets, and incidence of mid (7 – 14 d) embryo mortality. Using regular diets, 7 – 14 d embryo mortality is very rare being in the order of 0.1%. However, as vitamin deficiencies progress, there is a dramatic increase in mid-term embryo mortality and so this can be used as a diagnostic tool in troubleshooting problems with hatchability. Observations on malformations and malpositioned embryos indicate no clear trend, inferring limitations of these parameters as diagnostic indicators of practical-type vitamin deficiencies in breeder diets.

Vitamin deficiencies, of course, should not occur under commercial conditions because all requirement needs should be met with synthetic sources in the premix. In fact, breeder diets often contain the highest levels of supplemental vitamins of any class of poultry, and this is some times questioned as being too costly. In feeding breeders we not only want to prevent signs of deficiency as detailed previously, but also to ensure optimum production and hatchability. The superior performance of breeders that we routinely see today, with peaks of 85 – 88% will only be achieved by feeding relatively high levels

Table 6.38 Common embryo deficiency symptoms for vitamins and minerals

Nutrient	*Deficiency symptoms*
Vitamin A	*Early embryo mortality (48 hours) with failure to develop circulatory system.*
Vitamin D_3	*Depending on reserves in dams, stunted chicks and soft bones. Usually associated with shell defects and hence changes in porosity of the shell.*
Vitamin E	*Usually see early embryo mortality at 1 – 3 d. Encephalomalacia may be seen in the embryo and exudative diathesis is common.*
Riboflavin	*Excessive embryo mortality 9 – 14 or 17 - 21 days. Embryos show edema and clubbed down. Chicks may show a curling of the toes.*
Pantothenic acid	*Subcutaneous hemorrhages in unhatched embryos.*
Biotin	*Reduced hatch without reduced egg production. Peak in embryo mortality during first week and last 3 days of incubation. May see skeletal deformities and crooked beaks.*
Vitamin B_{12}	*Embryo mortality around 8 – 14 days, with possibly edema, curled toes and shortening of the beak.*
Thiamin	*There are two stages of embryo mortality – one very early and the other at 19 – 21 d. Many dead chicks appear on the trays although there are few, if any, deformed chicks. Mortality can be high for 10 – 14 days for those chickens that do hatch. Injecting the chicks with thiamin results in an almost instantaneous recovery. Certain types of disinfectants, anticoccidials and poor quality fish meal have been implicated in thiamin deficiencies. There is also recent evidence to suggest that thiamin requirements are increased in the presence of some Fusarium molds.*
Calcium and phosphorus	*As maternal deficiency progresses, embryo mortality shifts from later to earlier stages of incubation. Shortened and thickened legs are seen with shortened lower mandible, bulging forehead, edema of neck and protruding abdomen. Shell quality is usually affected.*
Zinc	*Numerous skeletal deficiencies, and feather down may appear to be 'tufted'.*
Manganese	*Late embryo mortality (18 – 21 days). Embryos show shortened wings and legs with abnormal head and beak shape. Edema is common and feather down is usually abnormal.*

Table 6.39 Hatchability of eggs produced by caged breeders fed corn-soybean diets devoid of supplemental vitamins (% fertile eggs)

	Vitamin omitted from control diet							
Week on diet	*None (control)*	*Biotin*	*B_{12}*	*E*	*Folacin*	*Niacin*	*Pantothenate*	*Riboflavin*
1	95	86	97	97	97	96	94	95
3	97	83	95	84	89	87	81	55
5	98	63*	84	67	30*	61*	74*	19*
7	92	54*	61*	62*	19*	69	26*	1*
13	88	52	27*	95	38*	50	54	0*
15**	90	96	21*	75	70	38*	56	0*
17	95	90	50	58*	85	61	40*	57*
19	97	99	99	92	99	98	97	96

* *Significantly different from control ($P < 0.05$).*
** *Vitamins reintroduced.*

of vitamins as part of a balanced nutritional program.

One reason for higher vitamin fortifications relative to standards, such as NRC (1994), is the loss in potency of vitamins that can occur between feed manufacture and consumption by the bird. Different vitamins are susceptible to various stresses to varying degrees, but as a generalization it can be stated that the major causes of loss of vitamin potency are storage time, storage temperature, and storage humidity of the premix before mixing, and of the feed after mixing. Another major loss of vitamins occurs if they are premixed with minerals and stored for 3-4 months prior to incorporation in feed. Also, conditions within the premix and feed can cause loss of potency. For example, some vitamins are acidic whereas others break down under acidic conditions. Finally, to really cause problems to vitamin stability, we sometimes pellet feed, and here the temperature and humidity can cause vitamin breakdown. Most companies consider high levels of vitamin fortification to be essential and economical for optimum hatchability and early broiler performance. In most locations, vitamins E, A, biotin and riboflavin are the most expensive vitamins within a premix, representing 60 – 70% of total cost.

6.9 Caged breeders

The dwarf bird seems an ideal candidate for cage management although there are serious problems seen when regular size breeders are caged for any length of time. Commercial trials with regular breeders, involving artificial insemination, have generally proven unsuccessful due to lack of uniformity and foot pad lesions. Both of these problems seem to relate to feeding management, and the propensity of the regular sized breeder to become overweight. Few mechanical systems are able to accurately dispense feed to each cage, and so over/under-nutrition becomes a problem. Our experiences with field trials indicate that most often, in a cage containing three breeder hens, while 'average weight' may be ideal, there will often be three distinct sized birds which is likely related to aggression and dominance behavior within the group.

Feed allocation is also difficult to regulate as mortality progresses, since for most systems, it means physically moving birds so as to maintain a constant number per cage. Footpad lesions often develop after 35 weeks of age, especially with overweight birds. Until a simplified and accurate feed allocation system is developed for cage systems, it is doubtful that they can be made to operate economically under commercial conditions. We have experienced similar problems with a new colony cage system involving twenty breeder hens and two roosters per cage. Again foot pad lesions become problematic after peak egg production.

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FEEDING PROGRAMS FOR TURKEYS

CHAPTER 7

7.1 Commercial turkeys

Genetic potential for growth rate of turkeys continues to increase, and standards for male turkeys are now close to 1 kg per week of age at marketing weights of 18 – 20 kg. Unlike most other meat birds, there are distinct differences in the market weights of males and females and so it is accepted that the sexes must be grown separately. Male turkeys are now commonly grown to 18 – 24 weeks of age, and females to 15 – 16 weeks of age. A proportion of females will be sold as whole carcasses, while males are usually further processed in some way. A growing concern with these large turkeys is integrity and quality of the breast meat, since PSE (pale soft exudative) meat, as sometimes occurs in pigs, is now raised as an issue during processing. There has been no major change in carcass fat:protein over the last few years, and so meat quality is the main concern regarding carcass quality. Other carcass defects, such as breast buttons and other skin abnormalities are often a factor of management rather than genetics or nutrition *per se*.

There still needs to be some flexibility in developing feeding programs for turkeys. The diet specifications shown in Table 7.1 are general guidelines that can be used for both male and female turkeys. Depending on the marketing age of hens, the diets will perhaps be scheduled a little more quickly and/or the last diet used is a compromise between the Developer #2 and Finisher as shown in Table 7.1. The turkey will grow quite well on a range of diet nutrient densities, although grow-out time will increase and classical feed utilization will decrease, with lower nutrient dense diets. Poorer performance than expected with some high energy diets is often a consequence of not adjusting amino acid levels to account for reduced feed intake. Examples of diets based on corn and soybean meal are shown in Table 7.2 and growth standards are shown in Table 7.3.

Breast muscle deposition is now maximized at around 18 weeks of age in large toms, with deposition of about 65 g/d. Deposition of leg and thigh muscle on the other hand plateaus early, at around 14 weeks of age when there is a maximum daily deposition of about 45 g. Nutrient specifications from the commercial breeding companies are detailed in Tables 7.4 and 7.5.

Table 7.1 Diet specifications for growing turkeys

	Starter	Grow 1	Grow 2	Dev 1	Dev 2	Finisher
Age (wks)	***0 – 4***	***5 – 8***	***9 – 11***	***12 - 14***	***15 - 16***	***17+***
Crude Protein (%)	28.0	26.0	23.0	21.0	18.0	16.0
Metabolizable Energy (kcal/kg)	2850	2900	3050	3200	3250	3325
Calcium (%)	1.40	1.25	1.15	1.05	0.95	0.85
Available Phosphorus (%)	0.75	0.70	0.65	0.60	0.55	0.48
Sodium (%)	0.17	0.17	0.17	0.17	0.17	0.17
Methionine (%)	0.62	0.56	0.52	0.48	0.42	0.35
Methionine + Cystine (%)	1.05	0.93	0.84	0.75	0.68	0.58
Lysine (%)	1.70	1.60	1.45	1.30	1.12	1.00
Threonine (%)	0.90	0.87	0.82	0.76	0.68	0.61
Tryptophan (%)	0.28	0.26	0.23	0.21	0.19	0.16
Arginine (%)	1.75	1.65	1.55	1.40	1.20	1.10
Valine (%)	1.20	1.10	1.00	0.90	0.78	0.65
Leucine (%)	1.90	1.80	1.65	1.50	1.25	1.10
Isoleucine (%)	1.10	1.00	0.94	0.82	0.72	0.65
Histidine (%)	0.60	0.55	0.50	0.44	0.35	0.30
Phenylalanine (%)	1.00	0.90	0.82	0.73	0.63	0.55
Vitamins (per kg of diet)	100%	100%	90%	80%	70%	60%
Vitamin A (I.U.)	10,000					
Vitamin D_3 (I.U.)	3,500					
Vitamin E (I.U.)	100					
Vitamin K (I.U.)	3					
Thiamin (mg)	3					
Riboflavin (mg)	10					
Pyridoxine (mg)	6					
Pantothenic acid (mg)	18					
Folic acid (mg)	2					
Biotin (μg)	250					
Niacin (mg)	60					
Choline (mg)	800					
Vitamin B_{12} (μg)	20					
Trace minerals (per kg of diet)						
Manganese (mg)	80					
Iron (mg)	30					
Copper (mg)	10					
Zinc (mg)	80					
Iodine (mg)	0.5					
Selenium (mg)	0.3					

Table 7.2 Examples of turkey diets (kg)

	Starter	Grow 1	Grow 2	Dev 1	Dev 2	Finisher
Corn	473	535	535	605	680	690
Soybean meal	350	350	349	266	195	180
Corn gluten meal	80	26				
Meat meal	60	60	60	60	60	60
AV Fat			31	46	44	55
DL-Methionine*	1.2	1.2	1.3	1.3	1.1	0.5
L-Lysine	2.5	1.6	0.2	1.4	1.9	0.9
Salt	2.3	2.3	2.4	2.4	2.4	2.4
Limestone	15.0	10.3	9.4	7.9	6.6	6.0
Dical Phosphate	15.0	12.6	10.7	9.0	8.0	4.2
Vit-Min Premix**	1.0	1.0	1.0	1.0	1.0	1.0
Total (kg)	1000	1000	1000	1000	1000	1000
Crude Protein (%)	28.7	26.0	24.2	21.0	18.2	17.5
ME (kcal/kg)	2890	2900	3050	3200	3250	3325
Calcium (%)	1.50	1.25	1.15	1.05	0.95	0.85
Av Phosphorus (%)	0.75	0.70	0.65	0.60	0.55	0.48
Sodium (%)	0.17	0.17	0.17	0.17	0.17	0.17
Methionine (%)	0.62	0.56	0.52	0.48	0.42	0.35
Meth + Cys. (%)	1.05	0.95	0.89	0.75	0.68	0.60
Lysine (%)	1.70	1.60	1.45	1.30	1.10	1.00
Threonine (%)	1.10	1.06	1.00	0.87	0.76	0.74
Tryptophan (%)	0.35	0.34	0.33	0.28	0.23	0.22

** or equivalent MHA*
*** with choline*

Table 7.3 Performance standards for commercial turkeys

	Weight	Age	F:G	ADG
Male	15 kg	18 wk	2.60	110 – 130 g[1]
Female	7.5 kg	14 wk	2.25	77 – 90 g

[1]Higher value denotes European standards using higher nutrient dense diets.

Table 7.4 Strain comparison for commercial heavy male turkeys

	Starter (0-4 wks)			Finisher (16 – 20 wks)		
	BUT	Hybrid	Nicholas	BUT	Hybrid	Nicholas
ME (kcal/kg)	2900	2850	2910	3300	3520	3420
CP (%)	-	27.5	25 – 27.0	-	16.0	14 – 17.0
Ca (%)	1.40	1.40	1.45	1.07	0.90	0.85
Av P (%)	0.78	0.75	0.74	0.62	0.45	0.38
Na (%)	0.16	0.17	0.17	0.18	0.18	0.18
Methionine (%)	0.70	0.69	0.58	0.49	0.36	0.34
Meth + Cys (%)	1.25	1.17	1.02	0.88	0.65	0.56
Lysine (%)	1.92	1.80	1.70	1.04	0.80	0.80
Threonine (%)	1.22	-	1.04	0.66	-	0.53

Table 7.5 Vitamin and trace mineral needs of commercial turkeys (0-4 weeks)

Nutrient	/kg	BUT	Hybrid	Nicholas
Vitamin A	IU	15,000	10,000	14,000
Vitamin D_3	IU	5,000	5,000	5,000
Vitamin E	IU	50	100	50
Vitamin K	mg	5	4	4
Folic acid	mg	3	2.5	4
Niacin	mg	75	100	55
Pantothenic acid	mg	25	25	28
Riboflavin	mg	8	15	10
Thiamin	mg	5	4.5	4
Pyridoxine	mg	7	5	6
Biotin	µg	300	300	200
Choline	mg	400	1,200	1,600
Vitamin B_{12}	µg	20	40	20
Copper	mg	20	15	25
Zinc	mg	100	160	100
Iron	mg	50	80	45
Manganese	mg	120	160	120
Selenium	mg	0.2	0.3	0.4
Iodine	mg	2	3	3

a) Starter diets and poult viability

Feeder management and feed texture are just as important as feed formulation in influencing early poult growth. Poults are much more reluctant to eat mash rather than crumbled feed, and this phenomenon is most evident in the 7 – 14 d growth period (Table 7.6).

Quality crumbles and then quality pellets are important to ensure optimum feed intake. During the first week, poults should not have to move too far to find feed and water. It is good management practice to 'overfill' feeders at this time, to ensure easy access to feed, even though this creates some feed wastage.

There has always been higher mortality in the first week in turkeys compared to chickens. Mortality of 1 – 2% in the first 7 d is still common, and in part, this may relate to feeding program. As its name implies 'starve-out' is caused by failure of poults to eat and/or drink, even though feed is apparently readily accessible. For whatever reasons, metabolic conditions cause lethargy in some poults and they seem reluctant to feed and drink. The situation may be compounded by hatchery conditions such as beak trimming, vaccinating, detoeing and desnooding of male poults.

Intentionally depriving poults of feed for 48 hr on average has little effect on 7 – 10 d body weight or intestinal morphology at this time. Certainly 3 – 4 d body weight and intestinal growth are affected by such starvation, although compensatory growth seems to occur if conditions are ideal for such growth. Under commercial conditions where multiple stressors are possible, then it may take longer than 7 – 10 d for growth compensation to occur.

The poult is hatched with very low available energy reserves, and glycogen is most likely synthesized by gluconeogenesis from protein. Attempts at improving glycogen/energy reserves in the poult have generally had little beneficial effect. In the past, poults have been given glucose solutions prior to transport from the hatchery. Recent data suggests that while this may have very short-term benefits (2 – 3 hrs maximum) the glucose uptake likely suppresses key enzymes, so suppressing glycogen synthesis, and this can be detrimental to subsequent longer-term health status. Injecting alanine, a non-essential amino acid, has been shown to elevate blood glucose levels without the concomitant reduction in glycogen reserves. However, the long-term benefits with alanine injection are difficult to quantitate, even in terms of 7 d mortality. Propionate is also a precursor of glucose, and has been fed to young poults. However propionate is also an anorexic agent, and so this is counterproductive to ensuring long-term benefits for the poult.

Table 7.6 Effect of feed texture on growth rate of poults (g)

Poult age (d)	*Mash*	*Quality crumbles*	*Difference (%)*
7	*117*	*140*	*20*
14	*250*	*320*	*28*
21	*450*	*600*	*30*
28	*780*	*1020*	*30*

Adapted from Nixey (2003)

Table 7.7 Nutrient digestion of 49 d old turkeys previously infected with PEMS at 5 d of age

	49 d digestibility		
Bird type	***Nitrogen (%)***	***Fat (%)***	***AMEn (kcal/kg)***
Non-infected	*64.6*^{a}	*85.9*^{a}	*3470*^{a}
Infected – large wt.	*59.1*^{b}	*80.8*^{ab}	*3270*^{b}
Infected – medium wt.	*61.4*^{ab}	*78.5*^{b}	*3190*^{b}
Infected – small wt.	*58.4*^{b}	*78.3*^{b}	*3180*^{b}

Adapted from Odetallah et al. (2001)

There has also been concern about the vitamin E status of the young poult. Vitamin E levels in the liver and serum of poults reach alarmingly low levels 2 – 3 weeks after hatch. For example, while poults may show 80 µg vitamin E/g liver at hatch, the normal levels at 21 d are closer to 0.5 µg/g. Sell and co-workers at Iowa State have investigated this problem, and while significant treatment differences are sometimes seen, normal blood and liver values are still in the order of magnitude as described previously. For example, feeding the medium chain fatty acids as found in coconut oil, rather than tallows or even sucrose, does seem to change vitamin E status, yet after 21 d, liver levels are still less than 1 µg/g tissue. It therefore seems very difficult to stop this 'natural' decline in vitamin E status, and obviously, the poults' immune status is being questioned relative to these changes. Because vitamin E plays a number of roles in the body, it is possible that fat levels and fat oxidation may influence general health status of the young poult. However adding extra antioxidants has not generally been beneficial. Likewise adding bile salts to the diet does little to improve vitamin E status of the poult, and so absorption *per se* is not thought to be a limiting factor.

There are a number of health issues that influence early poult development, and perhaps the formulation of starter diets. Poult enteritis and mortality syndrome (PEMS) has been a serious problem in isolated regions of the world. The condition is likely caused or accentuated by the presence of viruses, and poults can be artificially infected by dosing with intestinal contents from other infected birds. While high mortality is sometimes experienced, there is a secondary problem of stunting, where affected birds do not show compensatory growth. Recent data suggests that turkeys that recover from PEMS have impaired digestion/absorption of most nutrients (Table 7.7). At 49 d, turkeys were selected as large, medium or small depending on their recovery characteristics from PEMS infection at 5 d. Regardless of turkey size, there was a general trend for reduced nutrient digestion, suggesting that early PEMS infection has a long lasting detrimental effect on intestinal morphology.

There is some controversy regarding the use of fat in diets for young poults. High fat diets have been advocated to ease the shift towards glycolysis after hatching and there is the suggestion that this situation improves early growth rate. Advocates of high fat starter diets indicate that diet energy levels should not be increased, and that fat merely replaces carbohydrate as a source of energy.

Variable results to such formulations may be related to saturation characteristics of the fat being used. The young poult seems somewhat better than the chick in digesting saturated fatty acids, yet when these predominate, overall digestibility is quite low (Table 7.8).

The saturates C16:0 and C18:0 are fairly well digested when in the presence of a large quantity of unsaturates as occurs in soybean oil. This synergism likely relates to ease of micelle formation, which is a necessary prerequisite of transport from the lumen to the brush border of the epithelium, digestion and subsequent absorption. When there are minimal unsaturates available for micelle formation, then digestion of saturates is exceptionally low, not getting much over 50% by 21 d of age. Since medium chain unsaturates such as C8:0 and C12:0 in ingredients like coconut oil, do not necessarily need prerequisite micelle formation or action of bile salts then they are better absorbed by young birds (Table 7.9).

The digestion of medium chain fatty acids is exceptionally high, even for very young poults, and so these provide a viable alternative to other, possibly more expensive, vegetable oils containing unsaturates. There is also some research suggesting that three week old turkeys metabolize corn with about 10% less efficiency compared to 17 week old birds.

So-called Field Rickets continues to be an ongoing problem at certain farms. Since some farms seem to have greater occurrence than do others, there has always been suspicion of an infectious agent. However, when homogenates from the digesta of affected poults are fed to normal birds, there is no effect on poult liveability or skeletal development. Obviously, dietary levels of calcium, phosphorus and vitamin D_3 come under close scrutiny, but rickets does not seem to be a simple deficiency of any one of these nutrients. There are reports of prevention from using $25(OH)D_3$ rather than vitamin D_3, while other

Table 7.8 Digestibility of C16:0 and C18:0 fatty acids within soybean oil and tallow (%)

		C16:0		C18:0	
		Soybean oil	Tallow	Soybean oil	Tallow
Poult	7d	96	65	51	50
	21d	99	59	51	36
Chick	7d	81	35	73	6
	21d	94	54	88	31

Adapted from Mossab et al. (2000)

Table 7.9 Fat digestion by young poults

	Lipid digestibility (%)		
Diet	3-5d	6-8d	9-11d
1. Corn-soy	74^b	76^b	78^b
2. 1 + 10% AV-fat	69^c	72^b	71^c
3. 1 + 10% MCT[1]	90^a	92^a	90^a

[1]Predominantly C8:0
Adapted from Turner et al. (1999)

workers claim the condition is caused by an as yet unidentified antinutrient.

Formulating high protein/amino acid starter diets using only vegetable proteins presents some unique challenges. When animal proteins are excluded from the diet, the most common change in formulation is to use more soybean meal. In order to achieve 28 – 29% CP and associated levels of amino acids, then it is necessary to use around 50% soybean meal in these all-vegetable diets. When meat meal is available, the level of soybean is closer to 35% of the diet. While 50% soybean ensures that amino acid needs can be met, this high level of inclusion does pose problems with elevated levels of potassium and oligosaccharides. Because soybean meal is a low energy ingredient, a high inclusion level also poses problems of 'space' within the formulation. The levels of threonine and arginine in the diet also need more careful scrutiny. There is little that can be done to resolve the problem of indigestible oligosaccharides, since as yet, there are not any really effective exogenous enzymes that can be used to aid digestion of these complex carbohydrates. High levels of potassium lead to wetter litter and more problems with footpad lesions. It is possible to maintain electrolyte balance by using less salt, more sodium bicarbonate and in extreme cases, by adding ammonium chloride to the diet. Maintaining electrolyte balance by these means may be most beneficial when round heart disease (spontaneous cardiomyopathy) is problematic since occurrence can be limited by maintaining MEq at 230 vs. 250-320 as often occurs in high soybean meal prestarters.

With the high levels of lysine needed in prestarter/starter diets, there is often concern about the need for arginine. The usual recommendation is to have arginine at 110% of lysine, and so when lysine is at 1.7%, arginine needs are close to 2% of the diet. This level of arginine may be difficult to achieve with higher levels of animal protein, and under these situations, arginine at 102% of lysine is more economical.

b) Heavy turkey programs

With continued improvement in genetic potential of large strain turkeys, there is the possibility to continually extend market weight. Most large white male strains today are capable of sustained high ADG through to 23 – 24 kg liveweight. At this end of the spectrum, nutritional programs aimed at sustaining skeletal integrity and manipulating the balance of carcass fat:protein become more critical. As a generalization, the young turkey is most responsive to amino acids, while economic growth of the larger bird is more related to energy intake. There have been major changes over time in the type or genetics of turkeys available for production. Today, such differences are less evident as all breeding companies strive to aim for larger birds grown to older market ages. This later maturing type of turkey, which has been very common in Europe for many years, is now becoming the standard 'type' worldwide, and so today, there is less emphasis on 'strain-specific' feeding programs.

In diets composed essentially of corn and soybean meal, methionine and/or TSSA are likely to be the limiting amino acid. Requirement for methionine will obviously vary with energy level of the diet, although it is possible to make general recommendations of around 2.4, 2.1 and 1.7 mg methionine per kcal ME for starter, grower/developer and finisher diets respectively. With later maturing turkey strains that are now used almost exclusively, higher levels of lysine

seem beneficial. Lysine levels are therefore around 6.5, 5.5 and 3.5 mg/kcal ME for starter, grower and finisher diets respectively. Most nutritionists consider the turkey to be very responsive to lysine levels, although as a percentage of crude protein, the levels used in practice are little different than for other meat birds. There is some evidence to suggest that toms and hens are not too responsive to higher levels of lysine assuming a balanced protein is being used.

Traditionally, the concept of optimum energy:protein has been considered for most classes of turkeys. Recent evidence suggests that this concept is no longer applicable, or at least not always economically viable. Sell and co-workers in an extensive series of studies, working with growing tom turkeys from 9 – 20 weeks of age, concluded that increasing CP or ME improved weight gain and feed:gain, but that the CP effect was independent of ME. It is perhaps pertinent that the energy response in this work in fact relates to added fat. Increasing the energy concentration of the diet reduced the quantity of protein consumed per kg of body weight gain, although it had no effect on ME consumed per kg of gain. Increasing the protein content of the diet reduced protein efficiency in relation to gain, although efficiency for ME was improved. Interestingly, these changes in diet specification had little effect on carcass composition. These workers conclude that optimum CP:ME as a constraint in formulation may be inappropriate, and that it may be better to consider independent effects for both protein and energy.

In meeting the nutrient requirements of turkeys, changes in diet specification with age are obviously a compromise in attempting to accommodate reduced requirements of older birds. With an 18 – 24 week growing period, the potential for diet change is much greater although they must obviously be balanced against practical considerations of feed manufacture and on-farm handling of many feeds. Many research studies in fact suggest that the number of diet changes, from as little as 2, up to 10, over an 18 week period have little effect on turkey performance. With fewer diet changes, there has to be more 'over formulation' to ensure that birds are not faced with deficient diets at the beginning period of feeding any one diet. Changing diet each 3 – 4 weeks seems to be a practical compromise. Fewer diet changes do pose problems in adjusting diet texture. While young poults require quality crumbles, the transition through to larger pellets is critical over the first 8 weeks of growth, and can only really be achieved with at least two changes in feed texture. Too large a pellet introduced too early invariably results in reduced feed intake and increased feed wastage.

Utilization of fats in diets for turkeys has always been a controversial topic and certainly one that has received considerable attention in recent years. In many instances, research protocols fail to differentiate between the effects of fat and energy. Considering the dominant role that energy plays in controlling growth, it is perhaps not too surprising that turkeys respond to supplemental dietary fat. At fixed energy levels, there is often improvement in feed:gain with added fat and this effect increases with increase in age of the bird. From 0 – 12 weeks, F:G is improved by about 1.5% for each 1% added fat. From 12 – 20 weeks, a corresponding value of 3.5% is seen. It is often noted that if fat is removed from the diet of older birds, then any improvements to that time are often lost. These data suggest little return in use of fat for young birds, and that economic response is maximized after 8 weeks of age. The age response is likely a reflection of improved digestibility of more saturated fatty acids coupled with the improved efficiency associated with direct

deposition of absorbed fats into body fat depots. The turkey's response to energy is to some extent influenced by environmental temperature.

Maximum weight gain for market weight birds is achieved at 10 – 16˚C. At 27˚C and 35˚C, gain is reduced by about 6% and 12% respectively although feed:gain is improved by 1.2% for each +1˚C up to 27˚C. It is generally recognized that amino acid levels in the diet should increase as temperature increases, because feed intake will decline. There are also advantages to increasing the fat and perhaps the energy content of diets for turkeys older than 12 weeks of age and necessarily maintained at >22˚C. As genetic potential increases, so the upper critical temperature for optimum growth rate will likely decline. In their publication, British United Turkeys predict that the maximum environmental temperature required for realizing maximum growth rate is declining by 2 – 3˚C each 10 years and for large toms now stands at close to just 10˚C. It seems that market weight declines by about 100 g for each 1˚C increase in environmental temperature above this 10˚C ideal. However, this increased growth is achieved by stimulation of feed intake and so feed efficiency will deteriorate at lower temperatures (Table 7.10).

Table 7.10 Performance of male turkeys grown at 15 or 25ºC

	25ºC	*15ºC*
134 d B.wt.(kg)	*17.72*	*18.83*
Feed intake	*43.64*	*49.05*
F:G	*2.41*	*2.53*
Breast (% carcass)	*31.9*	*33.3*

Adapted from Veldkamp et al. (2000)

In this study, growth rate and breast meat yield could not be sustained when birds at 25˚C were fed diets supplemented with additional methionine, lysine and threonine.

The large turkey would seem to be an ideal candidate for compensatory gain and in fact, the early work on such feed programs was demonstrated with turkeys. However, modern strains of turkeys do not seem to perform adequately on such diets, and growth compensation is rarely achieved. It seems as though slow initial growth brought about by using low nutrient dense starter diets compromises the bird to such an extent that 18-week weight is 5 – 7% below standard. With lower protein starter diets, there is a suggestion that amino acid levels other than methionine and lysine should be more closely studied. With starter protein levels as low as 22% CP, threonine and valine levels may be equally as important as lysine, and interaction among branched-chain amino acids may be problematic. For example, high levels of leucine seem to cause growth depression in low protein starter diets, and this effect is only partly alleviated by additions of valine. Such data suggest caution in the use of high leucine ingredients such as corn gluten or blood meal in compensatory growth type feeding programs. More recent studies on compensatory gain have generally failed to show any distinct advantage in terms of overall feed usage or cost/kg gain, and in fact complete growth compensation to a specific age is sometimes not realized. For example, feeding low protein starter diets for just the first 3 weeks, followed by normal diets, has been shown detrimental to 18-week body weight. It seems as though the later maturing strains common today are not ideal candidates for compensatory growth. Their genetically inherent slower initial growth, in

effect, parallels the concept of compensatory growth and it appears that these birds are unable to fully recover from a period of early under-nutrition. For market ages of 16 – 20 weeks, compensatory growth therefore has limited application. The concept will likely be re-visited as market weights increase further.

There have been numerous research projects looking at low crude protein, amino acid fortified diets, ostensibly as a means of reducing feed cost or in order to reduce manure nitrogen content. When diets are formulated to 80% of normal levels of crude protein, then body weight can often be normalized by supplementing with methionine, lysine and threonine. However, in most of these studies, even though growth may be normal, there is often loss in breast meat yield. With low protein diets there is usually loss in feather cover. The length of tail feathers is often used as an indicator of feather development, and it seems that there is a linear relationship between this characteristic and diet protein/amino acids. It seems that tail feather length decreases by about 2 mm/1% CP by 6 weeks of age. This is equivalent to about 2% loss in tail feather length per 1% CP. However, since such diets often impair growth rate *per se,* it is not clear if this delayed feathering is merely a correlate of reduced growth. Of the amino acids tested to date feather development seems most responsive to methionine.

Two reoccurring problems in the industry are so-called flushing syndrome, which appears as diarrhea, and turkey knockdown, which disables older turkeys. Both problems may have a nutritional component, although it is obvious that other, yet unknown factors, are also involved. As its name implies, flushing syndrome is characterized by wet, runny excreta that is seen in commercial flocks from 6 – 14 weeks of age, although most commonly during 8 – 12 weeks. Because this timing coincides with removal of anticoccidials from the diet, there has been speculation about associated changes in intestinal microflora. The wet litter increases the potential for leg disorders and breast blemishes. Wetter excreta can be caused by high levels of minerals and especially salt and also by excess protein which both relate to increased water consumption. However, the flushing syndrome is associated with a 'sticky' type of excreta, whereas extra salt and protein usually cause watery and urate-dense excreta respectively.

Surprisingly, diet fiber level and source have little effect on cecal and excreta appearance. The occurrence of flushing at 8 – 12 weeks coincides with increase in fat content of the diet and so various levels and sources of fat, and also fats with various degrees of rancidity have been tested, again without any consistent effect. The only diet nutrient that consistently affects the degree and consistency of cecal excreta, is copper. Adding 500 g copper sulphate/tonne feed results in greater cecal evacuation and the cecal excreta are of much greater viscosity. Cecal excreta contains as much as 14,000 ppm copper. Certainly not all turkeys are fed additional copper sulphate, although it does appear to contribute to abnormal excreta consistency. Other attempts at diet modifications used to treat or prevent flushing syndrome have generally met with little success. There are some reports of benefit to adding 2 kg betain/1000 litres of drinking water.

Turkey knockdown also occurs at around 10 – 14 weeks of age where affected birds are unable to stand or walk. The condition resembles ionophore toxicity, but this has largely been ruled out as a single causative factor.

Knockdown is most severe when there is a repetitive on-off lighting program and turkeys are seen to 'gorge' feed when lights are turned on after a prolonged period of darkness. This latter situation is especially relevant when turkeys have limited access to water. Because of the implications of high feed intake over a short period of time, associated high intakes of ionophores have been suspected. However, under controlled studies when turkeys are encouraged to gorge on feed containing even 140 ppm monensin, no knockdown was observed.

With large turkeys there is now concern about quality of breast muscle. A condition comparable to Pale Soft Exudative (PSE) meat seen in some pigs, now appears in breast meat of large turkey males. In pigs, PSE is known to be an inherited trait. The changes to the breast meat are obvious with visual examination, and there are distinct microscopic alterations to breast muscle morphology. The condition becomes most problematic during further processing and slicing of breast meat. There does not seem to be a direct effect of nutrition. PSE is only seen in conjunction with fast growth rate, and the condition can be eliminated by slowing down growth by various means. PSE is not likely a factor of size of individual muscle fibers, because when restricted fed birds eventually catch up in weight, their fiber size is similar, yet PSE is rare. Muscle creatine kinase, which is an indicator of muscle 'damage' is greatly increased with conventional *ad–lib* feeding and in birds of similar weight, is always higher in *ad-lib* vs. restricted fed birds. In the swine breeding industry, the reaction of the pig to the anesthetic halothane was used as a screening test. This test does not seem to work with turkeys. The swine industry now uses a genetic marker test to screen carriers of the gene.

c) Broiler turkeys

There has been a decline in production of broiler turkeys, essentially due to competition with large roaster chickens. None of the commercial breeders now have a strain specifically designed for this market.

Feeding programs for small females essentially entail quicker scheduling of diets with earlier moves to higher energy diets. It is very difficult to obtain sufficient fat depots on males for this 6 – 6.5 kg broiler category and so they are rarely used for this purpose. Turkey hens will be around 5 kg at 10 weeks and 6.5 kg at 12 weeks with feed conversion at 1.8 – 2.0. The male of these strains is commonly taken to 10 –12 kg liveweight, again for the whole bird market. A feeding program for turkey hens to 12 weeks of age with 6.5 kg liveweight, is shown in Table 7.11.

Table 7.11 Diet specifications for broiler turkey hens

	Starter	*Grower I*	*Grower II*	*Developer*	*Finisher*
	0 - 4 wk	*5 – 6 wk*	*7 – 8 wk*	*9 – 10 wk*	*11 – 12 wk*
CP (%)	*29.0*	*26.5*	*24.0*	*21.0*	*19.0*
ME (kcal/kg)	*2850*	*2975*	*3075*	*3200*	*3300*
Ca (%)	*1.4*	*1.3*	*1.2*	*1.1*	*1.0*
Av P (%)	*0.80*	*0.75*	*0.65*	*0.55*	*0.50*
Na (%)	*0.17*	*0.18*	*0.18*	*0.19*	*0.19*
Methionine (%)	*0.65*	*0.62*	*0.58*	*0.52*	*0.45*
Meth + Cys (%)	*1.20*	*1.10*	*1.00*	*0.92*	*0.85*
Lysine (%)	*1.80*	*1.70*	*1.60*	*1.45*	*1.25*
Threonine (%)	*1.20*	*1.10*	*1.00*	*0.90*	*0.80*

d) Carcass composition

With an increased proportion of large turkey carcasses being cut-up or further processed, there is a continued demand for information on carcass yield and composition of turkeys. Due to dramatic changes in weight-for-age of the turkey, information regarding carcass composition for specific ages of bird becomes virtually redundant overnight. For this reason, we have presented the following carcass data based on expected changes related to age of turkey hens and toms (Table 7.12). In order to use this information, the coefficients for a particular parameter are multiplied by 'age-in-days' and '(age-in-days)^2'.

eg: % total viscera for a 100 d tom is calculated as

$$\mathbf{17.87 - (0.158 \times 100) + (0.00054 \times 100^2)}$$

$$\mathbf{= 17.87 - 15.8 + 5.4}$$

$$\mathbf{= \underline{7.47\%}}$$

Similarly, Table 7.13 gives expected changes in cut-up yields for toms and hens.

Table 7.12 Relationships between turkey age (days) and body weight and organ proportions. For each parameter, the first line represents toms, the second line hens

	Constant	±	Age	±	Age^2	Coefficient	
						Age	Age^2
As % of body weight:							
Total viscera ♂	17.870	-	.158	+	.000544	**	**
♀	18.696	-	.180	+	.000772	**	**
Liver	2.792	-	.0204	+	.0000673	**	**
	3.023	-	.0247	+	.0000824	**	**
Heart	.798	-	.00653	+	.0000267	**	**
	.766	-	.00681	+	.0000284	**	**
Alimentary tract	14.168	-	.129	+	.000400	**	**
	14.924	-	.152	+	.000548	**	**
Gizzard + proventriculus	5.089	-	.0284	+	.0000258	**	NS
	5.455	-	.0458	+	.000134	**	**
Carcass fat (g)	62.990	-	5.309	+	.0929	**	**
	-55.970	+	.749	+	.0596	NS	**
Carcass CP (g)	-103.10	+	8.738	+	.0357	**	**
	-122.46	+	10.704	-	.00863	**	NS
Viscera fat (g)	3.516	-	.421	+	.0173	NS	**
	-26.375	+	.737	+	.0182	NS	**
Viscera CP (g)	-32.15	+	3.478	-	.00524	**	**
	-21.23	+	2.806	-	.00733	**	**
Total body fat (g)	66.506	-	5.729	+	.110	**	**
	-82.344	+	1.486	+	.0778	NS	**
Total body CP (g)	-135.269	+	12.216	+	.0305	**	**
	-143.692	+	13.510	-	.0160	**	NS
Total body fat (%)	5.708	-	.0565	+	.000698	**	**
	4.704	+	.00588	+	.000724	NS	**
Total body CP (%)	15.438	+	.102	-	.000545	**	**
	15.250	+	.0996	-	.00577	**	**

Table 7.13 Relationships between turkey age (days) and body weight and carcass proportions. For each parameter, the first line represents toms, the second line hens.

	Constant	±	Age	±	Age^2	Coefficient significance	
						Age	Age^2
% Neck ♂	9.126	-	.0267	+	.000121	**	*
♀	9.141	-	.0199	+	.0000192	*	NS
% Drumsticks	14.498	+	.00183	-	.000115	*	NS
	14.158	-	.0108	-	.0000366	NS	NS
% Thighs	16.013	-	.0194	+	.000104	NS	NS
	16.471	-	.0287	+	.000183	**	**
% Wings	14.852	+	.0458	-	.000493	**	**
	16.067	+	.00711	-	.000285	**	NS
% Back	18.398	-	.113	+	.000468	**	**
	19.203	-	.131	+	.000652	**	**
% Breast	26.653	+	.1233	-	.000167	**	NS
	26.525	+	.172	-	.000502	**	**
% Yield	58.260	+	.352	-	.00123	**	**
	55.932	+	.426	-	.00170	**	**

Nutrition and feeding management play a significant role in attempting to meet the processor's demand for leaner turkey carcasses/meat. While previous discussion has detailed the importance of energy and protein, rather than energy:protein in terms of conventional growth parameters, one must be aware of the importance of this balance in finisher diets as it influences carcass fat deposition. There seems little doubt that the turkey responds in a classical manner in this respect, in that wider energy:protein will lead to increased carcass fat and *vice versa*. In reducing the ratio of energy:protein, one obviously has the option of increasing protein/amino acids in relation to energy, or reducing energy while maintaining normal protein levels. For broiler turkey hens, widening the ratio of energy:protein ensures early deposition of subcutaneous fat, and hence higher grade.

7.2 Turkey breeder feeding programs

With increased genetic potential for growth rate of hens, as well as tom breeders, it is often necessary to practice some degree of nutrient restriction during the growing period. It is difficult to control body weight through use of very low nutrient dense diets, and so feed restriction is becoming a viable alternative. Diet specifications for juvenile breeders are shown in Table 7.14, and for adult breeders in Table 7.15. Examples of corn-soybean adult breeder diets are detailed in Table 7.16. For the larger strains, the hens will weigh around 12.0 – 13.0 kg at 30 weeks and eat 50 – 55 kg feed. Toms will likely be close to 23 kg at 30 weeks, and eat 100 kg in this growing period.

Table 7.14 Diet specifications for juvenile turkey breeders

	Starter	Grower 1	Grower 2	Develop	Holding
Age (wks) - Hens	***0 – 3***	***4 – 7***	***8 – 11***	***12 – 14***	***15 - lighting***
- Toms	***0 –4***	***5 – 8***	***9 – 12***	***13 – 17***	***18 - 30***
Crude Protein (%)	*26.0*	*23.0*	*21.0*	*16.0*	*12.0*
Metabolizable Energy (kcal/kg)	*2750*	*2800*	*2850*	*2850*	*2800*
Calcium (%)	*1.40*	*1.30*	*1.10*	*1.00*	*0.90*
Av. Phosphorus (%)	*0.80*	*0.70*	*0.60*	*0.50*	*0.45*
Sodium (%)	*0.17*	*0.17*	*0.17*	*0.17*	*0.17*
Methionine (%)	*0.65*	*0.60*	*0.46*	*0.35*	*0.30*
Methionine + Cystine (%)	*1.15*	*1.00*	*0.85*	*0.64*	*0.58*
Lysine (%)	*1.70*	*1.55*	*1.25*	*0.95*	*0.60*
Threonine (%)	*1.10*	*0.95*	*0.75*	*0.55*	*0.48*
Tryptophan (%)	*0.28*	*0.24*	*0.20*	*0.16*	*0.14*
Vitamins (per kg of diet)	*100%*	*100%*	*90%*	*80%*	*80%*
Vitamin A (I.U.)	*10,000*				
Vitamin D_3 (I.U.)	*3,500*				
Vitamin E (I.U.)	*100*				
Vitamin K (I.U.)	*3*				
Thiamin (mg)	*3*				
Riboflavin (mg)	*10*				
Pyridoxine (mg)	*6*				
Pantothenic acid (mg)	*18*				
Folic acid (mg)	*2*				
Biotin (µg)	*250*				
Niacin (mg)	*60*				
Choline (mg)	*800*				
Vitamin B_{12} (µg)	*20*				
Trace minerals (per kg of diet)					
Manganese (mg)	*80*				
Iron (mg)	*30*				
Copper (mg)	*10*				
Zinc (mg)	*80*				
Iodine (mg)	*0.5*				
Selenium (mg)	*0.3*				

Table 7.15 Diet specifications for turkey breeders

	Breeder 1	Breeder 2	Tom diet
Crude Protein (%)	16.0	14.0	13.0
Metabolizable Energy (kcal/kg)	2950	2900	2850
Calcium (%)	2.60	2.80	0.85
Av. Phosphorus (%)	0.40	0.35	0.25
Sodium (%)	0.17	0.17	0.17
Methionine (%)	0.34	0.30	0.28
Methionine + Cystine (%)	0.58	0.50	0.42
Lysine (%)	0.80	0.72	0.60
Threonine (%)	0.60	0.50	0.45
Tryptophan (%)	0.18	0.16	0.15
Arginine (%)	0.90	0.70	0.60
Valine (%)	0.64	0.55	0.50
Leucine (%)	1.05	0.85	0.75
Isoleucine (%)	0.65	0.55	0.50
Histidine (%)	0.30	0.25	0.22
Phenylalanine (%)	0.60	0.45	0.42
Vitamins (per kg of diet)			
Vitamin A (I.U.)	9,000		
Vitamin D_3 (I.U.)	3,500		
Vitamin E (I.U.)	100		
Vitamin K (I.U.)	4		
Thiamin (mg)	3		
Riboflavin (mg)	8		
Pyridoxine (mg)	5		
Pantothenic acid (mg)	18		
Folic acid (mg)	1		
Biotin (µg)	300		
Niacin (mg)	70		
Choline (mg)	900		
Vitamin B_{12} (µg)	16		
Trace minerals (per kg of diet)			
Manganese (mg)	80		
Iron (mg)	40		
Copper (mg)	12		
Zinc (mg)	80		
Iodine (mg)	0.45		
Selenium (mg)	0.3		

Table 7.16 Examples of turkey breeder diets (kg)

	Breeder 1	Breeder 2	Tom diet
Corn	700	755	560
Soybean meal	211	160	61
Wheat shorts			350
AV Fat	12.5		
DL-Methionine*	0.5	0.4	0.6
L-Lysine		0.8	1.0
Salt	3.2	3.2	3.0
Limestone	60.1	70.0	21.0
Dical Phosphate	11.7	9.6	2.4
Vit-Min Premix**	1.0	1.0	1.0
Total (kg)	1000	1000	1000
Crude Protein (%)	16.0	14.0	13.0
ME (kcal/kg)	2950	2900	2890
Calcium (%)	2.60	2.88	0.90
Av Phosphorus (%)	0.40	0.35	0.25
Sodium (%)	0.17	0.17	0.17
Methionine (%)	0.34	0.30	0.28
Meth + Cystine (%)	0.58	0.50	0.46
Lysine (%)	0.80	0.72	0.60
Threonine (%)	0.70	0.62	0.52
Tryptophan (%)	0.22	0.18	0.17

* or equivalent MHA
** with choline

a) Hens

As with any female bird, body weight and condition at maturity seem to be the key to successful reproductive performance. For most strains of Large White hens, it is no longer possible to use commercial-type meat bird rearing programs, because birds become overweight within the first 4 – 6 weeks of growth. The type of program as shown in Table 7.14 is commonly used for most strains of turkey hens. If slower early growth rate is required, then it is tempting to start birds on lower-nutrient dense grower diets. This concept has been used successfully with broiler breeder pullets. However, for the young breeder poult, we are faced with large changes in specification of many nutrients in grower, compared to starter diets. This is most critical with levels of calcium and phosphorus and so a common consequence of starting poults on grower diets, is the occurrence of rickets. If slower early growth is required in breeder hens, then it is necessary to formulate specialised low protein/energy diets.

There are conflicting reports of the benefits to accrue from restricted feeding of juvenile breeder hens. Reducing body weight by up to 40% at 16 – 18 weeks of age is often claimed to result

in more settable eggs. This situation assumes that hens are allowed to compensate in the 18 – 30 week period and attain 12.0 – 13 kg weight at this age. If hens are underweight at 30 weeks of age, there is invariably poorer adult performance. One major variable seems to be the season in open-sided houses, since restricted feeding is most beneficial for breeders maturing in the warmer summer months.

The key to successful rearing of the breeder hen lies in monitoring of body weight, and scheduling diets according to weight-for-age, similar to the concept previously described for Leghorn pullets. Depending upon individual flock circumstances, managers should be flexible in diet selection within a program (Table 7.14). For example, if hens do not gain weight for two weeks, then it may be necessary to feed a higher protein diet until desired weight-for-age is achieved. Due to its large body size, the breeder hen has a very large maintenance energy requirement. It is for this reason that the bird is greatly influenced by changing environmental conditions. For example, a small Leghorn bird is expected to be slightly smaller when grown in hot vs. cool environments. However, the same environment for the turkey breeder hen can mean the difference between the need to restrict feed vs. the need to stimulate growth. Managers should be acutely aware of this effect and be prepared for flexibility in feeding programs with changing environmental conditions.

If hens are to start producing eggs at around 32 – 33 weeks of age, then it seems necessary to induce a partial molt at 20 – 22 weeks of age, and to light stimulate all birds around 30 weeks of age. Such a molt is best achieved with a sudden reduction in day length from 14 – 16 hours down to 6 – 8 hours for a 10 – 11 week period. During this molt, hens should ideally lose all primary wing feathers, although in practice, the 10th primary is often carried over. During this period of molt, hens will invariably eat some of the dropped feathers, especially if straw is not used as litter. This behavior seems normal, and is not indicative of a sulfur-amino acid deficiency. Obviously, birds should be fed insoluble grit at this time.

The use of a pre-breeder diet is open to some debate. High nutrient dense pre-breeder diets are often used on the assumption that they will advantageously pre-condition the bird immediately prior to lay. This may be true if birds are underweight at this age, due to poor rearing management. However, for birds of ideal weight and condition, there seems no advantage to using pre-breeder diets. With other classes of stock, pre-breeder diets are often used in an attempt to stimulate medullary bone development as a pre-requisite to shell calcification. However, in relation to shell output, the turkey consumes significant quantities of calcium from breeder diets, and so there is likely less emphasis on medullary bone calcium. The turkey hen does however exhibit an unusual pattern of feed intake in relation to egg production (Figure 7.1).

Fig. 7.1 Feed intake pattern of adult breeder turkey hens.

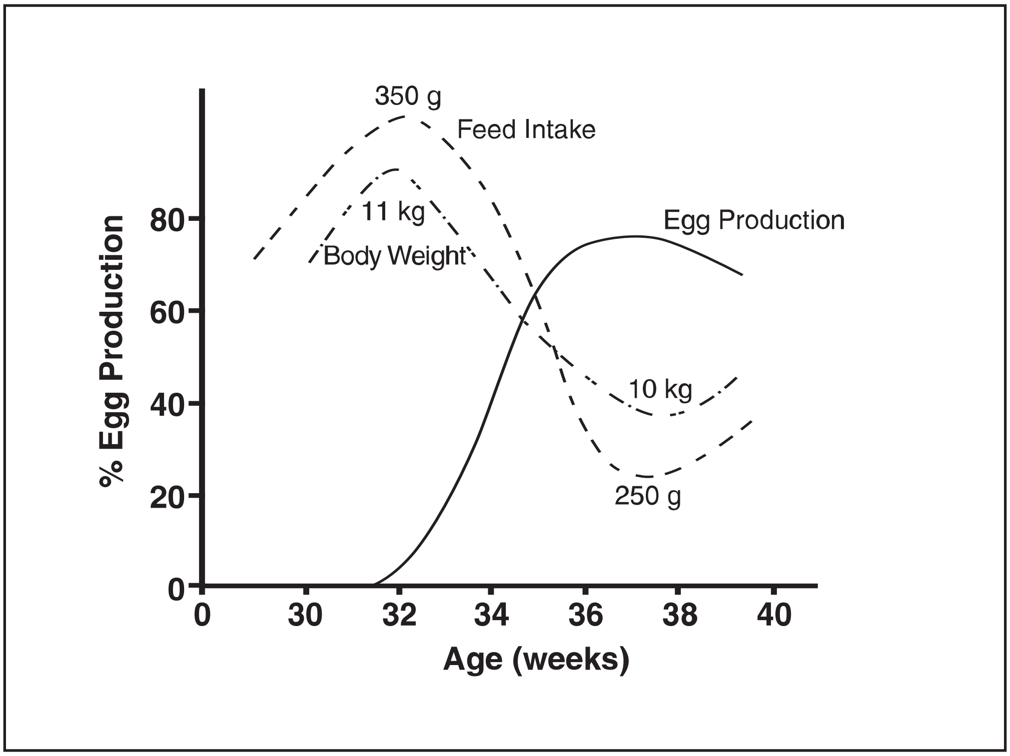
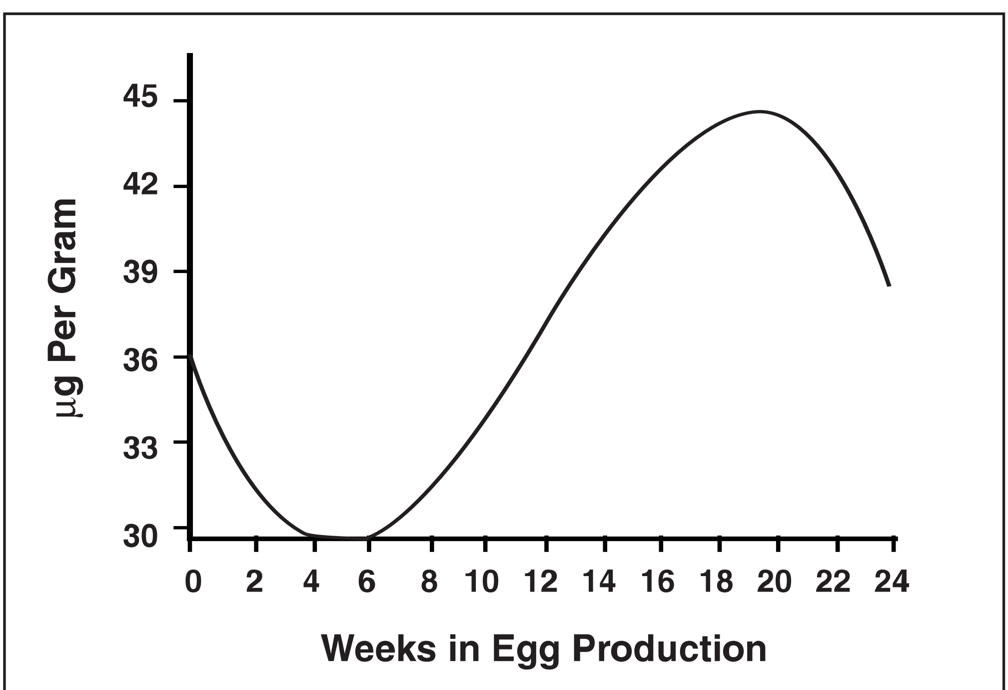


Fig. 7.2 Dry egg biotin content (Robel, 1983).



As the hen increases her egg production up to peak, she consumes a diminishing quantity of feed. In extreme cases, she may reduce feed intake from a peak of 300 g/d down to close to 200 g/d. At the same time, she is obviously increasing egg mass output, and so she will be in negative energy balance in terms of feed input:egg output. Such imbalance is obviously accommodated for by loss in body weight (Figure 7.1). The ability to lose up to 1 kg of body weight seems critical for optimum egg output, and this emphasizes the reasoning behind the importance of body weight and condition of the hen at 30 weeks of age. Unless nutritionists are aware of this inherent problem in breeder hens, and of the importance of tailoring diets according to mature weight, then variable responses to diets can be recorded. The positive response of turkey hens to added fat in the diet agrees with the general assumption of energy insufficiency at this time.

In addition to egg production, the feeding program must also accommodate optimum hatchability and poult quality. So-called 'first-AI' syndrome is common with the first few hatches from young flocks, where hatchability is suboptimal, and poult quality quite variable. Some tenuous relationships between this condition and nutrition of the breeder have been developed, although the condition invariably persists regardless of feeding program. The condition seems much worse with underweight birds, where presumably nutrient supply is limited. Under such conditions, vitamin supply is often questioned, although response to extra vitamins in the diet or water seems quite variable. There is some logical basis for extra vitamin supplementation at this time, because the content of some vitamins in the egg, such as biotin, seem suboptimal for the first few eggs produced by the turkey hen (Figure 7.2, Robel, 1983). Such changes in egg vitamin content may, however, be independent of nutritional status of the bird. Robel (1983) concludes that vitamin levels in the diet may be inadequate to sustain the original nutrient levels in eggs of turkey hens over the reproduction season, and that such inadequate levels may be causative in seasonal declines in hatchability.

A considerable number of turkey hens are being force-molted and used for a second cycle. An example of a molting program is given in Table 4.45. Guidelines to be followed during such a program are similar to those involved in rearing young hens, since body weight and condition at the start of the second cycle are again important. As shown in Figure 7.1, the hen regains weight after peak production, such that at the end of the first cycle she may be 0.75 – 1 kg heavier than her 30-week body weight. Ideally, the molting program will ensure that this weight is lost, so that the second cycle starts with a body weight once more at around 11-12 kg. In practice, hens are often heavier than this weight.

b) Toms

Considering the genetic potential of the male breeder turkey, it is obvious that some form of restricted feeding is essential. Such restriction results in smaller toms that are easier to handle in stud pens as well as birds of superior reproductive capacity. Restricted feeding programs usually involve diets of relatively low nutrient content (Table 7.14).

Seasonal decline in semen quality and quantity experienced with breeder toms can often be largely prevented through restricted feeding during rearing. Such males are easier to handle, and up to a 50% reduction in feed intake can be achieved. Hulet and Brody (1986) also

observed that toms were easier to handle following restriction to achieve 80 or 60% of the body weight of control-fed birds. These reductions in body weight were achieved with approximately 30 and 50% levels of feed restriction. These authors recorded no loss in reproductive performance.

Studies have been conducted with young growing tom breeder candidates in which protein levels have varied significantly. As expected, the lower the protein content, the smaller the bird, yet effects are not pronounced until diets of less than 12 – 13% CP are used after 10 weeks of age. Most turkey multipliers carry out quite severe selection at 16 – 17 weeks of age, at which time only 50 – 60% of toms may be considered as potential breeder candidates. Such selection is based on body weight, leg condition and general conformation. A criticism of using too severe a feed restriction program prior to this time is that there can be no selection against those birds exhibiting adverse characteristics associated with fast growth – the assumption being that their offspring may also show such characteristics. It is obviously more difficult to control growth after 17 weeks of age if high nutrient dense diets are used prior to this time in an attempt to simulate commercial growing conditions. Lower-protein diets used during rearing of toms also delays the onset of semen production, and this should be taken into account in placement time of toms and hens.

A problem sometimes encountered with breeder toms, is production of so-called yellow semen. Such semen is of inferior quality, and an incidence of up to 15% has been recorded in commercial flocks. There is some evidence linking a higher incidence with those toms fed low protein, low energy diets although the relationship is far from clear. When a high incidence of yellow semen occurs other environmental factors should also be investigated.

In those situations where physical daily feed restriction is not possible, then slowing growth through use of low nutrient dense diets after selection must be considered. It seems that 8 – 10% CP diets, of adequate amino acid balance, are suitable, although such specifications are often difficult to achieve in many geographical locations. Such low protein diets are most easily achieved with corn, and it is likely that this is the basis for recommending high energy levels (3000 kcal ME/kg) for such diets. While low protein-high energy diets may temper growth of toms in warm climates, these birds often overconsume energy in more temperate environments. Under these latter conditions, lower energy (2800 kcal ME/kg) levels are recommended.

In the stud pens, physical feed restriction is again an ideal management practice where most Large White strains will consume about 400 – 450 g each day. However, body weight monitoring must continue throughout this period, since it seems advantageous that the breeder tom gain weight, albeit very little (150 g/wk after 40 wks age). This can best be achieved by very small, but gradual increases in feed allowance each week.

c) Model predicted nutrient needs

An alternative system for defining nutrient requirements of breeders is to make predictions based on simple assumptions of need according to known inputs. For both breeder hens and toms body weight and growth are by far the largest input, and for the hen there is need to account for nutrients required for egg production.

In the following calculations, maintenance nutrient requirements were taken from data presented by Moran *et al*. (1983) and for the hen estimates of egg size, egg production and egg composition are used to calculate corresponding production requirements. Predictions for major nutrient needs of hens are shown in Table 7.17 and for toms in Table 7.18. Hens were assumed to have a body weight of 12.5 kg and be at 60% production with a 100 g egg. Tom needs were calculated based on body weight of 24 kg.

Data in Tables 7.17 and 7.18 show two major discrepancies between predicted levels and those provided by a typical commercial diet. For both hens and toms we seem to be overestimating needs for crude protein and greatly underestimating requirement for the amino acid cystine. The situation with cystine is of greatest concern, and the model prediction estimates are high because of the extensive need for maintenance related to feather regeneration. If these values are correct, then the only practical way of meeting such a requirement is to include feather meal in the diet and/or to use more synthetic methionine.

Table 7.17 Predicted daily nutrient requirements of turkey breeder hens

Nutrient	*Prediction*	*Diet specifications @ 250 g daily feed intake*	*Typical diet*
ME	*850 kcal/d*	*3400 kcal/kg*	*2970 kcal/kg*
CP	*24.9g*	*10.0%*	*17.0%*
Arginine	*1.9g*	*0.76%*	*0.95%*
Isoleucine	*1.5g*	*0.60%*	*0.75%*
Lysine	*1.3g*	*0.52%*	*0.85%*
Methionine	*0.5g*	*0.20%*	*0.42%*
Cystine	*1.3g*	*0.52%*	*0.24%*
Meth + Cyst	*1.8g*	*0.72%*	*0.66%*
Threonine	*1.2g*	*0.48%*	*0.55%*
Tryptophan	*0.3g*	*0.12%*	*0.14%*

Table 7.18 Predicted daily nutrient requirements of turkey breeder toms

Nutrient	*Prediction*	*Diet specifications @ 450 g daily feed intake*	*Typical diet*
ME	*1150 kcal/d*	*2550 kcal/kg*	*2750 kcal/kg*
CP	*36.2g*	*8.00%*	*12.0%*
Arginine	*2.8g*	*0.62%*	*0.61%*
Isoleucine	*2.2g*	*0.69%*	*0.53%*
Lysine	*1.7g*	*0.38%*	*0.60%*
Methionine	*0.5g*	*0.11%*	*0.20%*
Cystine	*2.2g*	*0.49%*	*0.18%*
Meth + Cyst	*2.7g*	*0.60%*	*0.38%*
Threonine	*1.7g*	*0.38%*	*0.42%*
Tryptophan	*0.3g*	*0.07%*	*0.11%*

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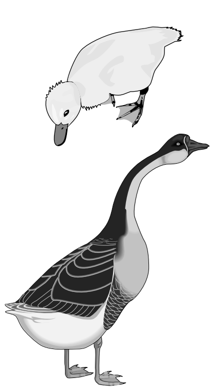
CHAPTER 8

FEEDING PROGRAMS FOR DUCKS & GEESE

Page

8.1 Ducks

The waterfowl industry has been relatively static in terms of overall production and marketing opportunities. There are now very few internationally recognized commercial breeders and so this leads to more standardization of performance. Asia, and particularly China, continue to be major producers of both meat and eggs, while eastern Europe is a major center of goose meat production. Interestingly the growth potential of Pekin type duck strains continues to still outperform that of modern broiler chickens.



Growth rate of meat ducks continues to improve on an annual basis, with males being around 3.2 kg at 42 d. Nutritional programs are aimed at finding a balance between expression of this growth rate vs. control of carcass fatness. Diet specifications for both commercial and breeder ducks are shown in Table 8.1, while examples of corn-soybean diets are shown in Table 8.2.

In formulating diets for meat ducks, care must be taken in adjusting the balance of protein:energy to try and minimize carcass fat deposition. The duck seems to respond in a similar way to protein:energy as previously described for the broiler chicken and turkey, such that higher protein diets in relation to energy generally result in less carcass fat. The duck seems to be able to digest fiber slightly better than does the chicken, and as such, metabilizable energy values for ducks may be 5 – 6% greater than corresponding values for chickens – such differences should be considered in setting energy specifications of diets.

Methionine and lysine are likely to be the most limiting amino acids in diets for ducks, and the normal base level of 2 and 5% of crude protein respectively seem applicable to the duck. Growth characteristics of Pekin ducks are shown in Table 8.3.

In developing feeding programs for ducks, carcass composition must be taken into account, especially for late-grower and finisher diets. Table 8.4 outlines the yield and commercial portions of Pekin ducks, while Table 8.5 details the fat and protein deposition in the carcass at 49 d of age. At 49 d of age, abdominal fat represents only some 2% of body weight, which is comparable to that found in chickens – this data confirms that the major problem with fat in the body of the duck is subcutaneous fat depots.

Table 8.1 Diet specifications for commercial and breeder ducks

Age (wks)	Starter (0 to 3)	Grower/Finisher (4 to 7)	Holding (8 – lighting)	Breeder (Adult)
Crude Protein (%)	22	18	14	16
Metabolizable Energy (kcal/kg)	2950	3100	2750	2850
Calcium (%)	0.85	0.75	0.75	3.0
Available Phosphorus (%)	0.40	0.38	0.35	0.38
Sodium (%)	0.17	0.17	0.16	0.16
Methionine (%)	0.48	0.38	0.3	0.40
Methionine + Cystine (%)	0.85	0.66	0.58	0.68
Lysine (%)	1.15	0.90	0.70	0.80
Threonine (%)	0.78	0.55	0.48	0.58
Tryptophan (%)	0.22	0.18	0.14	0.16
Vitamins (per kg of diet):	100%	90%	80%	100%
Vitamin A (I.U)	6000			
Vitamin D_3 (I.U)	2500			
Vitamin E (I.U)	40			
Vitamin K (I.U)	2			
Thiamin (mg)	1			
Riboflavin (mg)	6			
Pyridoxine (mg)	3			
Pantothenic acid (mg)	5			
Folic acid (mg)	1			
Biotin (μg)	100			
Niacin (mg)	40			
Choline (mg)	200			
Vitamin B_{12} (μg)	10			
Trace minerals (per kg of diet):				
Manganese (mg)	50			
Iron (mg)	40			
Copper (mg)	8			
Zinc (mg)	60			
Iodine (mg)	0.4			
Selenium (mg)	0.3			

Table 8.2 Diets for commercial and breeder ducks (kg)

	Starter	Grow/ Finish	Holding	Breeder
Corn	560	741	304	662
Soybean meal	275	184		200
Wheat Shorts	100	8.7	647	51
Meat meal	50	55	30	
DL-Methionine*	1.6	0.9	1.9	1.6
L-Lysine			1.9	
Salt	2.4	2.4	2.1	2.8
Limestone	10.0	7.0	12.1	71.4
Dical Phosphate				10.2
Vit-Min Premix**	1.0	1.0	1.0	1.0
Total (kg)	1000	1000	1000	1000
Crude Protein (%)	22.0	18.0	14.0	16.0
ME (kcal/kg)	2950	3100	2750	2850
Calcium (%)	0.87	0.75	0.75	3.00
Av Phosphorus (%)	0.41	0.39	0.35	0.38
Sodium (%)	0.17	0.17	0.16	0.16
Methionine (%)	0.52	0.40	0.40	0.44
Methionine + Cystine (%)	0.85	0.66	0.58	0.68
Lysine (%)	1.23	0.94	0.70	0.80
Threonine (%)	0.91	0.76	0.50	0.69
Tryptophan (%)	0.29	0.23	0.18	0.22

** or equivalent MHA*
*** with choline*

Table 8.3 Growth rate, feed efficiency and feed consumption of Pekin ducks

	Average weight (g)		Feed intake:body weight gain	
Weeks	♂	♀	♂	♀
1	500	490	1.2	1.2
2	1200	1140	1.6	1.6
3	1620	1570	1.7	1.8
4	2300	2100	1.8	2.0
5	2800	2600	1.9	2.1
6	3200	3100	2.0	2.2
7	3600	3400	2.2	2.3

Table 8.4 Yield and commercial cuts of Pekin ducks

	35 d		42 d		49 d	
	♂	♀	♂	♀	♂	♀
Eviscerated carcass (g)	1950	1850	2300	2150	2600	2350
Carcass yield (%)	70.5	72.0	73.0	74.0	75.0	76.0
% Thighs	14.0	12.4	13.7	13.0	12.2	11.2
% Drumsticks	13.7	13.5	12.5	12.2	10.6	10.3
% Wings	12.1	12.4	12.3	11.8	11.5	11.6
% Breast	17.0	18.9	20.5	21.7	25.7	26.5

Table 8.5 Carcass composition of male Pekin ducks

	35 d	42 d	49 d
Carcass fat (g)	480.3	632.1	785.0
Carcass CP (g)	100.3	66.4	72.8
Offal fat (g)	90.5	140.6	160.0
Offal CP (g)	98.2	94.5	106.5
Total body fat (g)	570.9	772.8	945.0
Total body CP (g)	343.3	394.7	459.0
Total body fat (%)	24.4	28.7	35.0
Total body CP (%)	14.8	14.6	17.0
Carcass fat as % body fat	84.2	81.8	83.0
Carcass CP as % body CP	71.3	76.0	76.7

The nutrient needs of the growing duck may vary depending upon consideration for weight gain, feed efficiency or carcass yield (Table 8.6).

If fast growth rate is desired, then there seems to be a distinct advantage to feeding good quality pellets. Ducks do not perform adequately on mash diets, a factor likely related to their inability to efficiently pick-up feed, and to do so without causing major feed wastage. The trend towards higher energy diets over the last few years, through use of dietary fat and higher levels of corn, leads to more problems in creating quality pelleted feed. Studies with 'wet' mash diets suggest improvements of liveweight and feed efficiency of around 5%. However these advantages are somewhat offset by the 'dirty' condition of the ducks, especially around the vent area.

High energy diets are often blamed for the high levels of fat seen in the carcass. However, the duck seems to eat to its energy requirement over quite a wide range of diet energy levels, and so it is not so obvious that high diet energy levels will lead to increased energy intake. In most instances, such high energy diets are not adjusted for crude protein content, and it is the balance of protein to energy that is most often the culprit that leads to increase in carcass fatness observed with high energy diets. There is reason to believe that the net energy of fat is increased when considerable portions of fat are being deposited in the carcass, and this

Table 8.6 Estimated amino acid needs of Pekin ducks (% of diet)

	0 – 21 d				21 – 49 d		
Parameter	*Lysine*	*TSAA*	*Threonine*		*Lysine*	*TSAA*	*Threonine*
Body weight	*1.16*	*0.76*	*>0.99*		*0.83*	*0.73*	*0.62*
Feed efficiency	*1.03*	*>0.87*	*0.98*		*0.73*	*>0.84*	*0.62*
Breast yield	*-*	*-*	*-*		*0.90*	*0.77*	*0.66*
Feed cost/kg gain	*0.94*	*0.87*	*0.82*		*0.74*	*>0.84*	*0.69*
Gross margin	*>1.21*	*>0.87*	*>0.99*		*0.87*	*>0.84*	*0.69*

Adapted from Lemme (2003)

situation does detract from the use of high energy diets. Due to the duck's apparent superior utilization of crude fiber, and the duck's ability to adjust feed intake to diet energy concentration, there seem to be advantages to using diets of medium-low energy concentration. In addition to tempering diet energy concentration as a means of controlling carcass fat content, there have also been reports of restricted feeding regimes, especially in the late-grower and finishing periods. Feed restriction *per se* does not seem to be as useful for controlling carcass fat as does attention to protein:energy in the diet, although a combination of the two systems may be feasible. As with any restricted feeding program, growth rate will be reduced, therefore producers must realize higher monetary returns from such leaner carcasses.

Discussion on the nutrition of ducks invariably includes their need for water. Water intake values are shown in Table 2.29. Ducks do have relatively high water requirements, and this is likely associated with the increased rate of passage of digesta. Reducing access time to water as a means of controlling litter moisture most often results in reduced feed intake and reduced growth rate, although two 4-hour periods of water access seems to be a compromise situation. Contrary to popular belief, there is no need to provide water such that ducks can either swim or immerse their heads, and so bell-type or even nipple drinkers are acceptable.

While most discussion to date has centered on the Pekin-type strains of meat bird, there is growing interest in the production of Muscovy ducks. This genetically distinct strain is most easily identified by the large sexual dimorphism in body weight (Table 8.7) with the male being at least 50% heavier at a slightly later marketing age. Muscovy ducklings seem to have a slightly lower protein requirement of around 21 and 19% CP respectively in starter diets for males and females. Requirements seem to decline to 14 – 17% CP in finisher diets for both sexes, although females are usually marketed some 2 – 3 weeks earlier than males in order to limit carcass fat deposition. The Muscovy may be an ideal candidate for programs involving compensatory growth.

Mule ducks have gained in popularity over the last few years, being a hybrid cross between Pekin and Muscovy. The main advantage of the sterile hybrid is that the males and females are of comparable weight, so removing the main obstacle associated with marketing of smaller Muscovy females. Typical growth rates of such hybrids are shown in Table 8.8.

Table 8.7 Performance of Muscovy ducks

Age (wks)	*Body weight (g)*		*Feed intake:body weight gain*	
	♂	♀	♂	♀
1	160	150	1.10	1.10
2	500	450	1.20	1.20
3	1000	900	1.40	1.42
4	1600	1300	1.60	1.75
5	2250	1800	1.80	1.90
6	2800	2100	1.95	2.05
7	3500	2350	2.10	2.15
8	4000	2500	2.20	2.30
9	4500	2700	2.32	2.50
10	4800	2900	2.40	2.62
11	5100	-	2.45	-
12	5400	-	2.60	-

Table 8.8 Growth and feed efficiency of hybrid Mule ducks

Age (weeks)	*Body weight (kg)*		*Feed efficiency*	
	♂	♀	♂	♀
3	1.0	0.9	1.32	1.54
4	1.6	1.4	1.41	1.63
5	2.2	1.9	1.54	1.75
6	2.8	2.5	1.63	1.84
7	3.4	3.0	1.71	1.90
8	3.9	3.5	1.82	2.00
9	4.2	3.8	1.91	2.14
10	4.6	4.1	2.04	2.26

All ducks are very susceptible to mycotoxins, and in particular aflatoxin. Levels as low as 30 – 40 ppb have been shown to impair protein utilization, while levels of 60 – 80 ppb can cause a dramatic loss in growth rate. With low protein diets, the symptoms are greatly accentuated, and onset occurs more quickly. Heavy metal toxicity has also been studied extensively with ducks, although much of this research seems directed at application of natural contamination in wild species. Most species of ducks seem very susceptible to such heavy metals as cadmium, lead and arsenic, although toxic levels should not normally be encountered in uncontaminated commercial feeds. There are few research reports detailing the nutrient requirements of egg-type duck strains such as the Khaki Campbell and Indian Runner. In fact, a review of the literature suggests that strains such as the Khaki Campbell can be offered diets comparable to brown egg strain chickens and that feeding management is also similar.

There seems to be an advantage to feed restriction in growing breeder candidates. Most breeding stock is selected from within commercial flocks at normal market age, and so there is a great challenge to 'hold' birds up to time of sexual maturity. Low nutrient dense holding diets (Table 8.1) fed on a restricted basis according to desired body weight seem to be the only practical method of both delaying sexual maturity and controlling mature body size. Without such control, egg production is often very poor, and fertility of males may be virtually non-existent. Under such conditions, breeder candidates should be fed according to body weight as was previously described for broiler breeder stock (Table 8.9).

Restricted feeding of juvenile breeders from 3 – 20 weeks results in greater numbers of settable eggs and some 10% improvement in fertility. As occurs with turkeys, ducklings from young breeders do not grow as well as do those from older birds, and this situation cannot be resolved by supplements to breeder diets (Table 8.1). Heavy breeder strains can also successfully be molted as discussed previously for chickens and turkeys. Table 4.45 gives a general outline of a molting program. As with other species the initial requirement is for loss of 25 – 30% of body weight, and this is achieved by feed withdrawal and reduction in day length. The body reserves of the breeder, and her ovary and oviduct are then re-established through gradual return to *ad-lib* intake of a breeder diet over a 5 – 6 week period.

Table 8.9 Effect of restricted feeding of juvenile breeders on the performance of breeders from 20 – 60 weeks of age

		Feeding system to 20 weeks of age		
		Ad-lib	***75% ad-lib***	***50% ad-lib***
Feed intake (kg)	*3 – 8 wk*	*7.4*	*5.6*	*3.7*
	8 – 20 wk	*17.3*	*13.0*	*8.7*
Body wt (kg)	*8 wk*	*3.1*	*2.8*	*2.1*
	20 wk	*4.0*	*3.4*	*2.5*
	60 wk	*4.3*	*4.1*	*3.8*
Eggs	*20 – 60 wk*	*163*	*180*	*187*
Fertility (%)	*20 – 60 wk*	*83*	*92*	*92*

Adapted from Olver (1995)

8.2 Geese

While geese can exhibit the most rapid growth rate of all domesticated poultry species, a major limitation of expanded commercial production is undoubtedly carcass quality. As for most waterfowl species, the goose has a propensity to deposit fat in the body, and it is evident that a large proportion of this very rapid growth appears as skin, feathers and body fat. When economically feasible, such concerns must be accommodated in the development of feeding programs. Diet specifications for commercial meat-type geese and breeders are shown in Table 8.10 while corresponding diet examples are shown in Table 8.11.

As most production systems for geese involve some time spent on pasture, then the actual choice of feeding program must accommodate the availability and quality of pasture. Regardless of rearing system, early growth rate is best optimized through use of pelleted starter diets for 3 – 4 weeks during which time goslings are usually confined. Subsequent grower and finisher diets can be fed as sole dietary sources, and it is under such conditions that optimum growth rate is often achieved. Differences in performance of Chinese x Embden geese related to rearing system is shown in Table 8.12

Growth rate and feed intake data for sexed Pilgrim geese reared under confinement are shown in Table 8.13. While confinement rearing, involving the sole use of complete diets, may result in the most rapid growth, extensive systems may be more economical. Alternate systems often involve a period on pasture and/or supplemental grain feeding. Because geese have voracious appetites, they are able to consume large quantities of forage, and in eating such large quantities their nutrient intake from this poorer quality feed is maintained at near normal levels. Nutrient intake under such conditions will obviously depend upon both quantity and quality of pasture, and in the latter context pasture management, as it relates to ruminant animals, can be applied. Geese seem to accept a range of quality roughages, including clovers, mixed grasses, cereals and corn-silage.

Depending upon the time of year, it is often difficult to get adequate finish on 'younger' birds on pasture. Full-feeding of finisher diets for the last 10 d is often necessary to provide adequate feathering with a minimum of pin-feathers. When weaning geese from, or to pasture systems, the allocation of complete feed should not change abruptly, rather the transition should occur over a 2 – 3 d period. For geese on pasture, or for birds supplemented with whole grains, insoluble grit should be offered at about 1 kg/100 geese/wk.

Table 8.10 Diet specifications for commercial and breeder geese

Age (weeks)	Starter (0 - 3)	Grower/Finisher (4 - market)	Holding (7 – lighting)	Breeder (Adult)
Crude Protein (%)	21	17	14	15
Metabolizable Energy (kcal/kg)	2850	2950	2600	2750
Calcium (%)	0.85	0.75	0.75	2.8
Available Phosphorus (%)	0.4	0.38	0.35	0.38
Sodium (%)	0.17	0.17	0.16	0.16
Methionine (%)	0.48	0.40	0.25	0.38
Methionine + Cystine (%)	0.85	0.66	0.48	0.64
Lysine (%)	1.05	0.90	0.60	0.66
Threonine (%)	0.72	0.62	0.48	0.52
Tryptophan (%)	0.21	0.18	0.14	0.16
Vitamins (per kg of diet):	100%	80%	70%	100%
Vitamin A (I.U)	7,000			
Vitamin D_3 (I.U)	2,500			
Vitamin E (I.U)	40			
Vitamin K (I.U)	2			
Thiamin (mg)	1			
Riboflavin (mg)	6			
Pyridoxine (mg)	3			
Pantothenic acid (mg)	5			
Folic acid (mg)	1			
Biotin (µg)	100			
Niacin (mg)	40			
Choline (mg)	200			
Vitamin B_{12} (µg)	10			
Trace minerals (per kg of diet):				
Manganese (mg)	50			
Iron (mg)	40			
Copper (mg)	8			
Zinc (mg)	60			
Iodine (mg)	0.4			
Selenium (mg)	0.3			

Table 8.11 Diets for commercial and breeder

	Starter	*Grow/Finish*	*Holding*	*Breeder*
Corn	504	613		514
Soybean meal	315	198	25	137
Wheat shorts	150	150	500	267
Barley			450	
Meat meal		15		
*DL-Methionine**	1.7	1.0	0.6	1.8
L-Lysine			0.5	
Salt	3.3	3.1	2.9	2.9
Limestone	16.4	12.7	15.0	67.0
Dical Phosphate	8.6	6.2	5.0	9.3
*Vit-Min Premix***	1.0	1.0	1.0	1.0
Total (kg)	1000	1000	1000	1000
Crude Protein (%)	21.7	17.7	14.0	15.0
ME (kcal/kg)	2870	2970	2600	2750
Calcium (%)	0.90	0.80	0.80	2.80
Av Phosphorus (%)	0.40	0.38	0.35	0.38
Sodium (%)	0.18	0.18	0.16	0.16
Methionine (%)	0.51	0.40	0.27	0.43
Meth + Cystine (%)	0.85	0.66	0.48	0.64
Lysine (%)	1.20	0.90	0.60	0.70
Threonine (%)	0.90	0.74	0.49	0.61
Tryptophan (%)	0.30	0.24	0.21	0.20

** or equivalent MHA*
*** with choline*

Table 8.12 Growth rate and feed consumption of White Chinese x Embden geese (mixed sex)

	Confinement reared			*Range reared (excludes pasture)*		
Age (wks)	*Average wt. (kg)*	*Cumulative feed consumption (kg)*	*Feed intake: body wt. gain*	*Average wt. (kg)*	*Cumulative feed consumption (kg)*	*Feed intake: body wt. gain*
3	1.68	2.6	1.55	1.59	2.6	1.66
6	4.20	8.4	2.00	3.80	6.0	1.60
9	5.74	17.1	2.99	4.98	9.6	1.93
12	6.71	23.8	3.56	5.80	16.2	2.75
14	7.10	28.6	4.03	5.95	18.6	3.14

Table 8.13 Growth rate and feed consumption of Pilgrim geese

Age (wks)	Average weight(kg)		Cumulative feed(kg)		Feed intake: body wt. gain	
	♂	♀	♂	♀	♂	♀
2	0.70	0.70	0.88	0.88	1.26	1.26
4	2.20	2.10	3.20	3.40	1.45	1.61
6	3.60	3.00	6.70	7.00	1.86	2.33
8	4.70	3.90	11.70	11.60	2.48	2.97
10	5.00	4.50	15.10	15.00	3.02	3.33
12	6.10	5.10	20.00	18.50	3.27	3.63
14	6.45	5.40	25.00	23.00	3.87	4.26

Table 8.14 Effect of diet protein and amino acid levels on performance of Embden geese

Diet crude protein (%)	Methionine (%)	Lysine (%)	Body wt. (kg)				Carcass fat (% DM)	
			21 d		63 d			
			♂	♀	♂	♀	♂	♀
22	0.36	1.25	1.76	1.68	4.8	4.3	49	54
20	0.34	1.10	1.80	1.63	5.0	4.4	50	53
18	0.31	0.96	1.75	1.64	4.9	4.4	49	50
16	0.29	0.81	1.60	1.55	4.7	4.4	51	53

The energy level of all diets should be considered in relation to the propensity for carcass fat deposition. It appears as though growth rate, and hence carcass fat content, are more sensitive to diet energy concentration than to inputs of protein and/or amino acids (Table 8.14).

In this study, Embden geese fed single diet programs varying in protein content from 22 – 16% exhibited comparable body weights and carcass composition at 9 weeks of age. Even when all diets were supplemented with additional methionine and lysine, there was no response in these performance characteristics. Failure to show a response to amino acid supplementation beyond 3 weeks of age suggests that with a 16% protein, corn-soybean meal diet the lysine requirement for maximizing subsequent gain is no higher than 0.8%. In this study, calculation of the ratio of protein consumed to protein appearing as edible carcass protein gave values ranging from 5 to 9% for the various diets, which is markedly lower than the values of around 15 and 21% reported for the chicken broiler and turkey, respectively. While feed wastage was relatively high in this study (Table 8.14), it would be expected to account for only a relatively small portion of the difference in protein utilization. Thus, while geese may be very fast growing animals, they appear to be extremely inefficient in converting dietary protein to edible carcass protein. However, it is obvious that in this particular study, as well as many other reports, the level of dietary protein fed was in excess of that required for optimum gain.

Geese seem to derive about the same amount of energy as do chickens from most feedstuffs. Their ability to perform adequately on high fiber diets is therefore a factor of increased feed intake, rather than improved digestibility. Geese are quite sensitive to a number of mycotoxins as previously described for ducks, and are also greatly influenced by anti-nutrients such as the trypsin inhibitor found in raw soybeans. This increased susceptibility to anti-nutrients is manifested as decreased feed efficiency rather than any direct effect on feed intake. In situations of reduced performance, such as occurs with raw soybeans, poor feathering is often an early indicator of potential problems. As with most species of waterfowl, stage and degree of feathering can have economic significance in terms of yield of feathers and/or incidence of pinfeathers. Most data suggest that geese are able to perform most economically on low energy, high fiber diets. This scenario usually implies access to pasture and/or whole grain as well as complete feeds. The capacity of the goose to consume large quantities of dry matter enables it to meet its nutrient requirements from a diet very high in fiber. The goose might provide an interesting alternative to ruminant animals in utilizing high fibrous forages.

Because geese produce relatively few eggs, their nutrient requirements for egg production are not greatly increased over maintenance – or at least not increased for any sustained period. In order to control body weight, breeder candidates should be offered holding diets soon after selection, and this feed offered on a restricted basis up to time of maturity. Specialized breeder diets can be introduced 2 – 3 weeks prior to anticipated first egg, or alternatively the birds fed increasing quantities of the holding diet together with 3 – 4 g calcium/d as large particle limestone or oyster shell. If breeders are retained for subsequent breeding seasons, then holding diets and/or grains with minerals and vitamins should be allocated according to maintenance of body weight.

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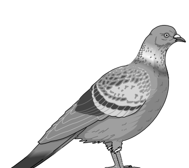
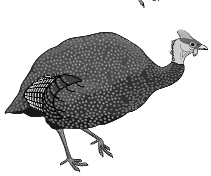
FEEDING PROGRAMS FOR GAME BIRDS, RATITES AND PET BIRDS

CHAPTER 9

9.1 Game birds

While there is some recent information on nutrient requirements of quail and pheasants, there is still a tendency to rely on trends occurring in turkey nutrition. A challenge in designing diets for game birds is varying market needs and especially commercial meat production vs. growing birds for hunting preserves or release. Birds grown for release generally do not need to grow at maximum rate and in many instances this is, in fact, a detriment to flying ability. Nutrient requirements and examples of diets shown in Tables 9.1 and 9.2 relate only to commercial meat production. For release programs, then some type of low nutrient dense holding diet is usually fed for example after 7 – 9 weeks of age with pheasants.





Pheasants – Table 9.1 outlines starter, grower, holding and breeder diet specifications for pheasants. The pheasant starter diet should be fed to 4 weeks of age, followed by the first grower diet to market age or until they are selected for breeding. Diets shown in Table 9.2 are complete diets and need not be supplemented with grain. However, the feeding of 5 to 10% cracked grain can be utilized after 12 weeks of age for birds that are to be released for hunting. The grain portion should be switched to whole grain at 16 weeks of age at which time one half of the feed allotment can be grain. Such a feeding program results in a stronger, hardier bird and one that is more able to forage for itself when released.

The pheasant breeder diet should be fed to the birds starting at least 2 weeks before eggs are expected. Again, this is a complete diet and no supplements should be added to it. Table 9.3 indicates weight gain and feed intake data for male and female pheasants to 18 weeks of age.

Quail – Quail diet specifications are shown in Table 9.4. The quail starter diet should be fed as a complete feed up to 6 weeks of age. At this time, the birds should be placed on the grower diet either until they are marketed as meat or until one week before table or hatching eggs are expected from the females. As mentioned above, a small percentage of scratch grain may be employed. Table 9.5 shows body weight and feed intake data for both male and female quail to 10 weeks of age.

Table 9.1 Diet specifications for commercial and breeder pheasants

	Starter	*Grow/Finisher*	*Holding*	*Breeder*
Age (wks)	*0 to 4*	*4 to market*	*12 – lighting*	*Adult*
Crude Protein (%)	27	21	15	16
Metabolizable Energy (kcal/kg)	2950	2950	2750	2800
Calcium (%)	1.30	1.10	0.85	2.60
Available Phosphorus (%)	0.60	0.48	0.42	0.42
Sodium (%)	0.18	0.18	0.18	0.18
Methionine (%)	0.60	0.46	0.35	0.42
Methionine + Cystine (%)	1.10	0.82	0.64	0.64
Lysine (%)	1.50	1.10	0.78	0.75
Threonine (%)	1.10	0.86	0.65	0.65
Tryptophan (%)	0.26	0.23	0.20	0.20
Vitamins (per kg of diet):	100%	80%	70%	100%
Vitamin A (I.U)	7000			
Vitamin D_3 (I.U)	2500			
Vitamin E (I.U)	40			
Vitamin K (I.U)	2			
Thiamin (mg)	1			
Riboflavin (mg)	6			
Pyridoxine (mg)	3			
Pantothenic acid (mg)	5			
Folic acid (mg)	1			
Biotin (µg)	100			
Niacin (mg)	40			
Choline (mg)	200			
Vitamin B_{12} (µg)	10			
Trace minerals (per kg of diet):				
Manganese (mg)	70			
Iron (mg)	40			
Copper (mg)	10			
Zinc (mg)	80			
Iodine (mg)	0.4			
Selenium (mg)	0.3			

Table 9.2 Diets for commercial and breeder pheasants (kg)

	Starter	*Grow/Finish*	*Holding*	*Breeder*
Corn	480	580	300	566
Soybean meal	418	247	14	177
Wheat shorts		96	615	180
Barley				
Meat meal	55	55	55	
Av Fat	17			
*DL-Methionine**	2.6	1.7	2.1	1.5
L-Lysine			1.3	
Salt	2.7	2.6	2.3	3.3
Limestone	15.5	13.6	9.3	60.0
Dical Phosphate	8.2	3.1		11.2
*Vit-Min Premix***	1.0	1.0	1.0	1.0
Total (kg)	1000	1000	1000	1000
Crude Protein (%)	27.0	21.0	15.5	16.0
ME (kcal/kg)	2950	2950	2750	2800
Calcium (%)	1.30	1.10	0.85	2.60
Av Phosphorus (%)	0.60	0.48	0.45	0.42
Sodium (%)	0.18	0.18	0.18	0.18
Methionine (%)	0.69	0.51	0.44	0.42
Meth + Cystine (%)	1.10	0.82	0.64	0.65
Lysine (%)	1.60	1.16	0.78	0.79
Threonine (%)	1.10	0.87	0.55	0.67
Tryptophan (%)	0.37	0.28	0.19	0.22

** or equivalent MHA*
*** with choline*

Table 9.3 Growth rate, feed consumption and feed efficiency of ring-necked pheasants

	Average weight (g)		*Cumulative feed consumption (g)*		*Feed efficiency*	
Age (wks)	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
2	85	85	144	144	1.71	1.71
4	220	200	430	416	1.98	2.07
6	380	350	866	794	2.23	2.28
8	620	520	1496	1352	2.43	2.61
10	830	660	2161	1915	2.61	2.88
12	1050	820	3136	2747	2.97	3.33
14	1300	960	4092	3640	3.15	3.78
16	1475	1025	5163	4709	3.51	4.59
18	1530	1080	6338	5827	4.14	5.40

Quail will likely be mature at around 7 – 8 weeks of age when body weight is around 150 - 160 g. Over a 15 week laying cycle, the breeders will produce about 80 eggs with hatch of those set around 80%.

Guinea Fowl – Although guinea fowl production has increased in North America over the last 10 – 15 years, the industry is still quite small compared to some parts of Europe and especially France. Diet specifications for growing and breeding guinea fowl are shown in Table 9.4. The starter diet is used to 4 weeks of age, followed by grower to market age of around 12 – 15 weeks depending upon needs of various weight categories. Growth rate and expected feed intake of male and female guineas are shown in Table 9.6.

Breeding females are switched to the guinea breeding diet shown in Table 9.4 approximately 2 weeks before eggs are expected. This is a complete diet and no grain or grit supplements need to be fed.

Table 9.4 Diet specifications for quail and guinea fowl

	Quail			*Guinea Fowl*		
	Starter	*Grower*	*Breeder*	*Starter*	*Grower*	*Breeder*
Crude Protein (%)	28	17	18	26	18	16
Metabolizable Energy (kcal/kg)	2900	2900	2950	2900	2950	2900
Calcium (%)	1.3	1.1	3.1	1.2	0.95	3.0
Av Phosphorus (%)	0.60	0.48	0.45	0.5	0.42	0.40
Sodium (%)	0.18	0.18	0.18	0.18	0.18	0.18
Methionine (%)	0.60	0.51	0.52	0.55	0.48	0.41
Methionine + Cystine (%)	1.10	0.80	0.82	0.92	0.82	0.75
Lysine (%)	1.30	0.90	0.85	1.20	0.95	0.80
Threonine (%)	1.10	0.85	0.78	1.00	0.85	0.71
Tryptophan (%)	0.24	0.22	0.22	0.22	0.21	0.18

Vitamins and trace minerals as per Table 9.1

Table 9.5 Mean body weight and feed intake of male and female Japanese quail to 10 weeks of age

	Male		*Female*	
Age (wks)	*Body wt. (g)*	*Cumulative feed intake(g)*	*Body wt. (g)*	*Cumulative feed intake (g)*
2	40	50	40	50
4	90	180	100	190
6	120	300	130	330
8	130	350	160	450
10	140	400	170	510

Table 9.6 Growth rate and feed intake of guinea fowl

	Body weight (g)		Feed intake (g/d)	
Age (wks)	♂	♀	♂	♀
1	70	90	13	18
2	140	175	23	27
3	250	270	36	39
4	400	400	50	50
6	750	700	58	56
8	1200	1000	65	60
10	1420	1300	75	70
12	1650	1550	75	70
16	1900	1800	75	70

9.2 Ratites

Ostrich and emu are the species most commonly farmed for meat, skin, feathers and other products such as preen gland oil. Traditionally South Africa has dominated world production of ostrich products, although in the mid 1980's there was great interest in ostrich farming in Europe and North America. Overproduction and limited market opportunities have now resulted in considerable reduction in ratite farming in these newer regions.

Ostriches are by far the largest birds of this group with adults reaching in excess of 150 kg. Hens can produce 20 to 40 eggs per year, each averaging around 1.25 kg.

Emus are about half the size of ostriches and while they produce a similar number of eggs as do ostriches, they are only about half the size. Emus are more docile than the ostrich and so easier to handle in confinement housing.

The large intestine of the ostrich is approximately 3 times the size of the small intestine, with food transit time of about 40 hours. The ostrich's digestive system is therefore adapted to handle large quantities of roughage material allowing it to obtain a significant portion of its energy from hind gut fermentation. The emu's digestive system, unlike that of the ostrich, is more like that of poultry, with rate of food passage being around 5 to 6 hours. Despite the apparent limitation in fermentation sites, there are reports suggesting that emus can digest more fibrous material than do other types of commercial poultry. Ostriches do not have a crop, and any feed storage occurs in an elongated proventriculus, which becomes prone to impaction with long stem fibrous ingredients. Diet specifications for ostriches are shown in Table 9.7.

Ostrich diets usually contain 6 to 15% fiber, depending on the age of the bird, while diets similarly vary in protein from 23 to 15%. It has been reported that the ostrich will metabolize 30 to 40% more energy from a diet than will poultry. This could account for some of the obesity problems seen in breeders fed 'poultry diets'. Metabolizable energy values for selected ingredients are shown in Table 9.8, confirming that ostriches have greater ability to digest high fiber ingredients.

Table 9.7 Diet specifications for ostriches

	Starter (0 – 8 wks)	Breeder[1]
Crude Protein (%)	18.0	15.0
Metabolizable Energy (kcal/kg)	2750	2650
Methionine (%)	0.36	0.30
Methionine + Cystine (%)	0.70	0.62
Lysine (%)	0.90	0.72
Calcium (%)	1.40	1.80
Av Phosphorus (%)	0.70	0.45
Sodium (%)	0.18	0.17

[1] *Plus free choice forage – actual energy level therefore reduced to equivalent of around 2300 kcal/kg*

Table 9.8 TME_n of selected ingredients for mature ostrich and cockerels (kcal/kg)

	Ostrich	Cockerel
Wheat bran	2844	2040
Common reed	2070	666
Lupins	3490	2240
Soybean meal	3210	2160
Sunflower meal	2600	2120
Fish meal	3620	3330

Adapted from Cilliers et al. (1999)

Table 9.9 Growth rate and feed intake of ostriches fed commercial diets

Age (wks)	Body wt. (kg)	Feed intake (g/d)
6	5.8	350
10	15.5	550
18	38.0	1300
26	55.0	2000
34	75.0	2500
42	90.0	2200
52	100.0	2000

Both the ostrich and the emu are prone to leg problems as well as apparent vitamin E and selenium deficiencies. Consequently, mineral fortification should be closely monitored, especially if forage or dehydrated alfalfa makes up a significant proportion of their diet. Vitamin E fortification of up to 80 IU/kg of diet is usually recommended, while selenium supplementation must remain within approved levels. At one week of age, ostrich chicks should weigh around 1 kg and by 4 weeks of age be close to 3 kg in weight. Table 9.9 details subsequent growth rate and feed intake.

After 4 to 6 weeks of age, liberal quantities of green forage can be offered to the birds either as a supplement or from pasture grazing. At 6 months of age, dietary protein level can be reduced to 13 to 15% with energy level remaining at 2700 – 2800 kcal ME/kg. Since ostriches make relatively good use of high fibrous feedstuffs, their diets can contain up to 20% fiber. Thus, liberal quantities of forage or alfalfa hay can be fed along with the prepared diet. Emus cannot handle as much fiber as do ostriches, and so their fiber intake should not make up more than 10 to 15% of their diet. Because of this high fiber intake, it is common practice to supply grit to the birds at least once a week.

Young ostrich and emu chicks have the tendency to search for and pick up any appropriate size material in their surroundings and so litter eating can be a problem in commercial units. To avoid this occurrence, chicks can be started on some type of rough paper or burlap. However, care must be taken to avoid anything with a smooth surface because ratite chicks are prone to leg problems. During the first week, the young chicks have a relatively slow rate of growth and growth rate is not constant as occurs with other meat birds. Growth in the first 7 – 10 d is quite slow and then this period is followed by maximum growth rate up to about 6 months of age. Subsequent slower growth continues up to maturity at around 30 months of age. Ostrich chicks suffer from leg problems similar to those seen with broiler chicks, although due to the relative size of the leg bones, such disorders are more easily noticed. Supplemental calcium feeding, as calcium borogluconate solution, seems useful for severely affected individuals, suggesting perhaps that attention should be given to calcium levels in the diet, and especially calcium availability of forages.

There is relatively little information available on carcass composition of ratites. Table 9.10 shows some carcass and body composition data of ostriches killed at 100 kg live weight.

Table 9.10 Carcass composition of 100 kg ostrich

	% Yield of live weight
Feathers	*1.8*
Blood	*3.0*
Hide	*7.0*
Feet	*2.5*
Carcass	*60.0*
Heart	*1.0*
Liver	*1.5*
Abdominal fat	*4.0*
Viscera	*8.5*

During the breeding season, the females markedly reduce their feed intake somewhat like a turkey breeder. Thus, it is important that they be in good condition carrying sufficient nutrient reserves, so that quality eggs are produced, leading to potentially healthy offspring. Table 9.11 shows gross composition of eggs from ostriches and emus.

Table 9.11 Ratite egg components

	Weight (g)	*Albumen (%)*	*Yolk (%)*	*Shell (%)*
Ostrich	*1200*	*54*	*32*	*14*
Emu	*600*	*53*	*34*	*13*

9.3 Pet birds and pigeons

Most pet birds are fed diets based on whole seeds rather than complete feeds as pellets. Feeding birds along the guidelines outlined in Table 9.12 would seem more logical from a nutritional viewpoint, although nutrition *per se* does not always seem to be the major factor involved in diet selection by owners.

Use of complete pelleted feeds has been met with resistance by owners, and not all species of bird readily accept conventional pellets. However, by using extruded pellets and incorporation of color/taste/smell additives both the owner and bird can be coaxed into using such complete feeds. There is increased demand for hand-reared birds due to better behavioral disposition and the potential for a ban in trade in exotic species. Consequently there is increased demand for information on diets for hand feeding of newly hatched birds. While many such hatchlings are fed on baby food/peanut butter mixes, a gruel formulated to the specifications shown in Table 9.12, and composed of more conventional ingredients, should prove more economical for large-scale operations. However, due to the monetary value of many of these pet birds, economics of nutrition is not always a major factor, especially when one considers the actual feed intake of these very small birds.

Table 9.12 Diet specifications for pet birds

	Budgie		*Parrots*		*Hand feeding*
	Young	*Adult*	*Young*	*Adult*	
Crude Protein (%)	*23.0*	*15.0*	*21.0*	*14.0*	*26.0*
Metabolizable Energy (kcal/kg)	*3000*	*2900*	*2900*	*2800*	*3200*
Crude fat (%)	*5.0*	*5.0*	*5.0*	*4.0*	*10.0*
Crude fiber (%)	*3.0*	*3.0*	*4.0*	*3.0*	*3.0*
Calcium (%)	*1.2*	*1.0*	*1.0*	*0.9*	*1.4*
Av Phosphorus (%)	*0.45*	*0.45*	*0.45*	*0.4*	*0.7*
Sodium (%)	*0.17*	*0.17*	*0.16*	*0.14*	*0.18*
Methionine (%)	*0.50*	*0.30*	*0.43*	*0.25*	*0.60*
Methionine + Cystine (%)	*0.92*	*0.61*	*1.00*	*0.52*	*1.20*
Lysine (%)	*1.30*	*0.75*	*1.20*	*0.68*	*1.40*

Mineral-vitamin premix as per turkey with 200 mg/kg Vit. C

For adults and young birds, that are self-feeding, then conventional ingredients as detailed in Chapter 2 can be considered. Fruit flavors may be an advantage with some of the more exotic species. Feed wastage can be a major problem with many pet birds, especially when pelleted feeds are first introduced to birds that are more accustomed to whole grain diets. Under these conditions, feed wastage can approach 10x that of the actual feed intake. Due to the difficulty of measuring feed wastage, and the obvious problem of equating feed intake with feed disappearance from the feeder, monitoring of body weight becomes the most rigorous criterion to be used in assessing any new feeding program. Regardless of the feeding program used, behavioral problems are often reduced if birds have access to other appropriate nutrient sources such as cuttle fish bones and/or fresh fruit etc.

Pigeon meat is often derived from squab, which is the name given to young pigeons that have been fed directly by the parents. Under the action of prolactin hormone, adult pigeons produce a secretion from the crop that is regurgitated and used by the hatchling pigeon. Pigeons are born blind and with few feathers, and rely soley on this crop milk for nourishment. The milk is around 25% solids, composed almost entirely of protein (18%) and lipid (7%). This very rich source of nutrients results in very rapid growth rate, measured at 4 times the rate of young 'broilers'. The squab will be around 500 g live weight at 28 d. There is an indication that crop milk production is reduced by feeding much less than an 18% CP diet to the adults. There are also reports of increased crop milk production following supplementation of their drinking water with L-carnitine. No one has yet been able to successfully grow squabs on a synthetic crop milk.

Adult pigeons are often fed mixtures of whole or cracked grains and protein feeds. The whole seeds are metabolized quite efficiently (Table 9.13).

Table 9.13 AMEn of various ingredients fed as whole seeds to adult pigeons

	AME_n (kcal/kg)
Corn	*3530*
Barley	*2950*
Sorghum	*3315*
Peas	*3350*
Sunflower	*5300*

Adapted from Hullar et al. (1989)

The adult pigeons need a diet providing around 18% CP and 2900-3000 kcal ME/kg while producing crop milk; 16% CP and 2800 kcal ME/kg during other times of the breeding season and 12 – 14% CP and 2600 kcal/kg as a holding diet between breeding seasons.

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Appendix 1. Basic nutrient composition

Ingredient	*Crude protein (%)*	*Digestible protein (%)*	*Metabolizable energy (kcal/kg)*	*Crude fat (%)*	*Crude fiber (%)*	*Calcium (%)*	*Available phosphorus (%)*	*Linoleic acid (%)*
Yellow Corn	8.5	7.8	3300	3.8	2.5	0.01	0.13	1.9
Wheat	13.0	11.6	3150	1.5	2.7	0.05	0.20	0.5
Oats	12.0	9.9	2756	4.0	12.0	0.10	0.20	1.5
Barley	11.5	9.3	2780	2.1	7.5	0.10	0.20	0.8
Milo	9.0	7.9	3250	2.5	2.7	0.05	0.14	1.0
Rye	12.5	8.4	2734	1.7	2.4	0.05	0.18	0.4
Triticale	15.4	13.2	3110	1.0	4.5	0.05	0.19	0.4
Rice (rough)	7.3	5.5	2680	1.7	10.0	0.04	0.13	0.6
Wheat bran	15.8	11.7	1580	4.8	10.4	0.10	0.65	1.7
Wheat shorts	15.1	14.3	2200	4.0	5.0	0.07	0.30	1.6
Wheat screenings #1	15.0	11.7	3000	4.1	3.0	0.05	0.20	0.7
Rice bran	13.0	7.7	1900	5.0	12.0	0.06	0.80	3.4
Rice polishings	11.0	8.5	2750	15.0	2.5	0.06	0.18	6.2
Bakery by-product	10.5	9.8	3500	9.5	2.5	0.05	0.13	3.0
Molasses (cane)	3.0	2.1	1962	-	-	0.50	0.03	-
Dehydrated alfalfa meal	17.0	9.5	1647	2.0	26.0	1.40	0.10	0.3
Canola meal	37.5	34.0	2000	1.5	12.0	0.65	0.45	0.5
Full-fat canola seed	22.0	19.7	4620	40.0	6.0	0.38	0.27	8.0
Soybean meal (48%)	48.0	44.0	2550	0.5	3.0	0.20	0.33	0.4
Full-fat soybeans	38.0	33.4	3880	20.0	2.0	0.15	0.37	0.3
Corn gluten meal	60.0	54.4	3750	2.51	2.48	0.10	0.28	9.0
Corn gluten feed	22.0	14.3	1830	2.5	10.0	0.40	0.21	1.22
Cotton seed meal	41.0	33.2	2350	0.5	14.5	0.15	0.40	1.0
Peanut meal	47.0	35.7	2205	1.0	13.0	0.20	0.45	0.21
Peas	23.5	20.7	2550	1.3	5.5	0.10	0.30	0.3
Safflower meal	42.0	32.9	1630	1.1	14.5	0.37	0.20	0.9
Sesame meal	44.0	30.6	1984	5.0	5.0	0.20	0.63	0.5
Sunflower meal	46.8	35.6	2205	2.9	11.0	0.30	0.75	2.0
Lupins	34.5	29.8	3000	6.3	16.0	0.20	0.50	1.8
Flax	22.0	18.1	3500	34.0	6.0	0.25	0.20	3.0
Meat Meal	50.0	45.0	2500	11.5	2.5	8.00	0.17	5.2
Fish meal (60%)	60.0	55.4	2750	2.0	1.0	6.50	4.00	1.82
Poultry by-product meal	60.0	52.5	2950	8.5	1.9	3.60	3.50	0.3
Blood meal	80.0	71.2	2690	1.0	1.0	0.28	2.10	2.5
Feather meal	85.0	75.7	3000	2.5	1.5	0.20	0.28	0.1
Dried Whey	13.0	12.4	1918	0.5	-	0.80	0.70	0.1

Appendix Table 2
Total amino acid composition

Appendix 2. Total amino acid compostion

Ingredient	*Methi -onine %*	*Cystine %*	*Lysine (%)*	*Hist -idine %*	*Trypt -ophan %*	*Thre -onine %*	*Arg -inine %*	*Iso -leucine %*	*Leu -cine %*	*Phenyl -alanine %*	*Val -ine %*
Yellow Corn	*0.2*	*0.11*	*0.2*	*0.2*	*0.1*	*0.41*	*0.4*	*0.5*	*1.0*	*0.5*	*0.4*
Wheat	*0.2*	*0.21*	*0.49*	*0.2*	*0.21*	*0.42*	*0.7*	*0.3*	*0.9*	*0.6*	*0.5*
Oats	*0.2*	*0.2*	*0.4*	*0.2*	*0.2*	*0.4*	*0.7*	*0.5*	*0.9*	*0.6*	*0.6*
Barley	*0.21*	*0.21*	*0.39*	*0.3*	*0.19*	*0.4*	*0.5*	*0.5*	*0.8*	*0.6*	*0.6*
Milo	*0.12*	*0.17*	*0.31*	*0.3*	*0.09*	*0.32*	*0.4*	*0.5*	*1.5*	*0.5*	*0.5*
Rye	*0.2*	*0.2*	*0.5*	*0.3*	*0.1*	*0.4*	*0.5*	*0.5*	*0.7*	*0.6*	*0.6*
Triticale	*0.2*	*0.2*	*0.4*	*0.3*	*0.1*	*0.3*	*0.8*	*0.5*	*1.0*	*0.7*	*0.7*
Rice (rough)	*0.12*	*0.11*	*0.22*	*0.2*	*0.11*	*0.34*	*0.6*	*0.3*	*0.7*	*0.3*	*0.5*
Wheat bran	*0.1*	*0.1*	*0.6*	*0.3*	*0.3*	*0.4*	*1.0*	*0.6*	*0.9*	*0.5*	*0.7*
Wheat shorts	*0.21*	*0.19*	*0.61*	*0.2*	*0.21*	*0.5*	*0.9*	*0.7*	*1.0*	*0.6*	*0.7*
Wheat screenings #1	*0.21*	*0.21*	*0.53*	*0.2*	*0.2*	*0.42*	*0.6*	*0.3*	*0.9*	*0.5*	*0.5*
Rice bran	*0.29*	*0.11*	*0.51*	*0.3*	*0.18*	*0.38*	*0.5*	*0.4*	*0.8*	*0.4*	*0.6*
Rice polishings	*0.21*	*0.29*	*0.50*	*0.2*	*0.12*	*0.32*	*0.6*	*0.3*	*0.7*	*0.4*	*0.7*
Bakery by-product	*0.21*	*0.19*	*0.29*	*0.3*	*0.13*	*0.3*	*0.5*	*0.4*	*0.8*	*0.6*	*0.5*
Molasses (cane)	-	-	-	-	-	-	-	-	-	-	-
Dehydrated alfalfa meal	*0.3*	*0.4*	*1.8*	*0.4*	*0.4*	*0.5*	*0.7*	*0.7*	*1.3*	*0.8*	*0.9*
Canola meal	*0.69*	*0.61*	*2.21*	*1.1*	*0.5*	*1.72*	*2.2*	*1.4*	*2.7*	*1.5*	*1.9*
Full-fat canola seed	*0.5*	*0.4*	*1.3*	*0.6*	*0.3*	*1.0*	*1.3*	*0.8*	*1.6*	*0.9*	*1.1*
Soybean meal (48%)	*0.72*	*0.79*	*3.22*	*1.3*	*0.71*	*1.96*	*3.6*	*2.6*	*3.7*	*2.5*	*2.5*
Full-fat soybeans	*0.49*	*0.63*	*2.41*	*0.9*	*0.49*	*1.53*	*2.7*	*2.0*	*2.8*	*1.9*	*1.9*
Corn gluten meal	*1.61*	*0.91*	*0.90*	*1.4*	*0.3*	*1.7*	*2.2*	*2.4*	*8.1*	*3.2*	*2.6*
Corn gluten feed	*0.4*	*0.5*	*0.6*	*0.7*	*0.2*	*0.9*	*1.0*	*0.6*	*2.4*	*0.7*	*1.0*
Cotton seed meal	*0.49*	*0.62*	*1.67*	*1.0*	*0.5*	*1.31*	*4.6*	*1.3*	*2.4*	*2.2*	*1.9*
Peanut meal	*0.4*	*0.7*	*1.6*	*1.2*	*0.5*	*1.5*	*4.9*	*2.0*	*3.0*	*2.7*	*2.8*
Peas	*0.3*	*0.2*	*1.6*	*0.7*	*0.2*	*0.9*	*1.4*	*1.1*	*1.8*	*1.9*	*1.3*
Safflower meal	*0.4*	*0.7*	*1.3*	*0.4*	*0.3*	*0.6*	*2.9*	*0.6*	*1.2*	*1.2*	*1.1*
Sesame meal	*1.5*	*0.6*	*1.4*	*1.2*	*0.8*	*1.7*	*5.1*	*2.3*	*3.2*	*2.3*	*2.5*
Sunflower meal	*0.8*	*0.7*	*1.6*	*1.0*	*0.9*	*1.6*	*3.3*	*1.8*	*2.4*	*1.9*	*2.2*
Lupins	*0.3*	*0.6*	*1.7*	*0.9*	*0.4*	*1.2*	*4.5*	*1.4*	*2.4*	*1.3*	*1.4*
Flax	*0.41*	*0.41*	*0.89*	*0.4*	*0.29*	*0.82*	*2.1*	*1.0*	*1.3*	*1.0*	*1.1*
Meat Meal	*0.71*	*0.61*	*2.68*	*0.7*	*0.36*	*1.52*	*3.0*	*1.3*	*3.3*	*1.6*	*2.4*
Fish meal (60%)	*1.82*	*1.1*	*5.28*	*1.6*	*0.58*	*3.01*	*4.0*	*4.1*	*5.0*	*2.7*	*3.6*
Poultry by-product meal	*1.3*	*2.0*	*3.4*	*1.0*	*0.4*	*2.2*	*3.5*	*2.1*	*4.5*	*1.8*	*3.0*
Blood meal	*1.0*	*1.4*	*6.9*	*4.2*	*1.1*	*3.7*	*3.5*	*1.0*	*10.0*	*6.0*	*7.0*
Feather meal	*0.6*	*5.5*	*1.72*	*0.5*	*0.6*	*4.51*	*6.4*	*4.3*	*6.5*	*4.3*	*7.4*
Dried Whey	*0.2*	*0.3*	*1.1*	*0.2*	*0.2*	*0.8*	*0.4*	*0.9*	*1.4*	*0.4*	*0.7*

Appendix 3. Available amino acid compostion

Ingredient	*Methi -onine %*	*Cystine %*	*Lysine (%)*	*Hist -idine %*	*Trypt -ophan %*	*Thre -onine %*	*Arg -inine %*	*Iso -leucine %*	*Leu -cine %*	*Phenyl -alanine %*	*Val -ine %*
Yellow corn	0.18	0.09	0.16	0.18	0.07	0.33	0.35	0.44	0.8	0.42	0.33
Wheat	0.16	0.17	0.40	0.18	0.17	0.32	0.56	0.26	0.81	0.54	0.42
Oats	0.18	0.18	0.37	0.18	0.18	0.34	0.64	0.45	0.81	0.55	0.50
Barley	0.16	0.16	0.31	0.26	0.15	0.29	0.41	0.41	0.73	0.53	0.48
Milo	0.09	0.15	0.23	0.26	0.06	0.24	0.28	0.42	1.30	0.40	0.40
Rice (rough)	0.09	0.06	0.17	0.17	0.11	0.27	0.50	0.26	0.56	0.28	0.41
Wheat bran	0.08	0.07	0.42	0.24	0.24	0.28	0.79	0.48	0.72	0.41	0.55
Wheat shorts	0.16	0.14	0.48	0.16	0.15	0.41	0.71	0.56	0.84	0.49	0.57
Rice bran	0.15	0.07	0.39	0.24	0.13	0.28	0.40	0.31	0.54	0.30	0.46
Rice polishings	0.16	0.08	0.41	0.18	0.08	0.25	0.48	0.27	0.57	0.31	0.52
Bakery by-product	0.18	0.16	0.19	0.24	0.08	0.21	0.40	0.32	0.71	0.51	0.40
Dehydrated alfalfa meal	0.21	0.16	1.00	0.29	0.28	0.35	0.56	0.51	1.00	0.55	0.70
Canola meal	0.61	0.47	1.76	0.93	0.38	1.30	1.92	1.04	2.40	1.30	1.55
Full-fat canola seed	0.40	0.26	1.00	0.48	0.24	0.81	0.98	0.62	1.28	0.72	0.81
Soybean meal (48%)	0.64	0.63	2.87	1.07	0.53	1.75	3.20	2.30	3.20	2.10	2.20
Full-fat soybeans	0.41	0.52	2.00	0.74	0.39	1.27	2.31	1.72	2.20	1.70	1.70
Corn gluten meal	1.44	0.78	0.81	1.14	0.21	1.58	2.07	2.30	7.90	3.10	2.40
Corn gluten feed	0.33	0.35	0.42	0.56	0.14	0.65	0.87	0.48	2.12	0.63	0.83
Cotton seed meal	0.35	0.40	1.18	0.69	0.35	0.90	3.68	0.95	1.72	2.00	1.70
Peanut meal	0.33	0.55	1.28	0.96	0.38	1.20	4.00	1.80	2.70	2.30	2.40
Sesame meal	1.30	0.54	1.30	1.00	0.60	1.43	4.60	2.00	2.80	2.10	2.30
Sunflower meal	0.72	0.55	1.30	0.80	0.65	1.20	2.64	1.28	1.90	1.55	1.75
Lupins	0.27	0.54	1.40	0.81	0.26	1.00	4.10	1.20	2.20	1.10	1.20
Flax	0.33	0.30	0.72	0.32	0.26	0.65	1.76	0.72	1.10	0.76	0.95
Meat meal	0.62	0.33	2.09	0.56	0.26	1.17	2.78	1.00	2.60	1.30	1.90
Fish meal (60%)	1.62	0.80	4.72	1.40	0.48	2.50	3.62	3.70	4.50	2.30	3.20
Poultry by-product meal	1.1	1.20	2.70	0.80	0.3	1.8	3.00	1.70	3.80	1.40	2.40
Blood meal	0.90	1.10	5.90	3.40	0.80	2.80	2.90	0.78	8.90	5.30	6.10
Feather meal	0.47	2.38	1.10	0.35	0.41	3.15	5.05	3.60	5.00	3.50	6.10

Appendix Table 4
Mineral composition

Appendix 4. Mineral composition

Ingredients	*Chloride (%)*	*Magnesium (%)*	*Sodium (%)*	*Potassium (%)*	*Iron (%)*	*Manganese (mg/kg)*	*Copper (mg/kg)*	*Zinc (mg/kg)*	*Selenium (mg/kg)*
Yellow Corn	0.05	0.15	0.05	0.38	0.01	4	3	29	0.04
Wheat	0.08	0.16	0.09	0.52	0.01	48	7	40	0.50
Oats	0.10	0.17	0.06	0.37	0.01	38	5	31	0.30
Barley	0.18	0.12	0.08	0.48	0.01	16	7	40	0.30
Milo	0.07	0.17	0.05	0.32	0.01	14	9	26	0.04
Rye	0.37	0.12	0.02	0.26	0.01	66	7	30	0.45
Triticale	0.41	0.15	0.04	0.41	0.01	51	6	35	0.43
Rice (rough)	0.28	0.14	0.03	0.34	0.01	15	3	10	0.17
Wheat bran	0.30	0.15	0.06	1.24	0.02	115	12	89	0.95
Wheat shorts	0.10	0.26	0.07	0.84	0.01	104	9	99	0.80
Wheat screenings #1	0.05	0.15	0.08	0.55	0.01	48	7	40	0.57
Rice bran	0.17	0.85	0.10	1.30	0.02	425	14	30	0.19
Rice polishings	0.17	0.65	0.10	1.17	0.02	310	8	30	0.17
Bakery by-product	0.48	0.20	0.53	0.62	0.02	30	7	41	0.30
Molasses (cane)	0.65	0.40	0.30	3.50	0.02	50	20	35	0.08
Dehydrated alfalfa meal	0.45	0.34	0.16	2.40	0.03	50	9	41	0.06
Canola meal	0.05	0.51	0.09	1.45	0.02	61	7	44	0.90
Full-fat canola seed	0.03	0.31	0.01	0.81	0.02	35	6	26	0.52
Soybean meal (44%)	0.05	0.25	0.05	2.61	0.02	32	35	54	0.12
Soybean meal (48%)	0.05	0.27	0.05	2.55	0.01	27	36	52	0.11
Full-fat soybeans	0.04	0.21	0.05	1.50	0.01	20	27	41	0.10
Corn gluten meal	0.06	0.05	0.10	0.04	0.04	7	28	66	0.30
Corn gluten feed	0.20	0.29	0.95	0.60	0.05	5	47	45	0.17
Cotton seed meal	0.03	0.39	0.05	1.10	0.01	18	16	40	0.06
Peanut meal	0.55	0.04	0.07	1.10	0.03	29	6	80	0.12
Peas	0.06	0.12	0.03	1.10	0.01	18	16	20	0.05
Safflower meal	0.03	0.27	0.10	0.69	0.03	24	9	80	0.13
Sesame meal	0.05	0.50	0.04	1.20	0.04	48	4	27	0.06
Sunflower meal	0.03	0.75	0.02	1.00	0.10	15	3	100	0.25
Lupins	0.01	0.13	0.10	1.00	0.01	70	4	30	0.18
Flax	0.05	0.30	0.08	1.20	0.02	74	17	91	0.11
Meat meal	0.90	1.00	0.50	1.25	0.04	18	8	98	0.40
Fish meal (60%)	0.55	0.21	0.47	0.32	0.06	25	8	119	1.85
Poultry by-product meal	0.40	0.18	0.36	0.28	0.05	20	6	79	0.90
Blood meal	0.26	0.14	0.33	0.21	0.03	6	8	80	0.60
Feather meal	0.40	0.20	0.70	0.30	0.05	15	12	7	0.72
Dried Whey	0.07	0.13	0.43	0.19	0.02	4	43	105	0.06

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